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THE DESIGN OF AXIAL COMPRESSOR AIRF LS
USING ARBITRARY CHAMBER LINES

George R. Frost, et al

Aerospace Research Laboratories
Wright-Patterson Air Force Base, Ohio

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THE DESIGN OF AXIAL COMPRESSOR AIRFOILS USING ARBITRARY CAMBER LINES

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FLUID DYNAMICS FACILITIES RESEARCH LABORATORY

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AEROSPACE RESEARCH LABORATORIES
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

1 a

FOREWORD

This report was prepared by Captain George R. Frost and Dr. Arthur J. Wennerstrom of the Fluid Dynamics Facilities Research Laboratory, Aerospace Research Laboratories, Wright-Patterson Air Force Base, Ohio.

The report presents results from a portion of the effort of the Fluid Machinery Research Group supervised by Dr. Arthur J. Wennerstrom and was conducted under Work Unit 09 of Project 7065, "Aerospace Simulation Techniques Research" under the overall direction of Mr. Elmer G. Johnson.

ABSTRACT

This report describes a technique which has been developed for use in the design of axial compressor airfoils with camber lines of arbitrary shape. The slope of the camber line at several points on a streamsurface is determined from the air angles at these points as well as the incidence and deviation angle distributions for the blade. A camber line is produced by fitting a smooth curve segment through each pair of points from the leading to the trailing edge. A thickness distribution is applied to this camber line to produce the blade element. A computer program which uses this technique to produce blade elements, stack them, and then determine coordinates for plane surfaces through the resultant blade is also described.

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INTRODUCTION

The traditional approach to the selection of blades for axial-flow compressors has been to choose a specific type of airfoil, subsequently to adjust the parameters defining that airfoil to suit prevailing aerodynamic conditions. Many successful designs have been accomplished in this manner using such blades as NACA 65-series, double circular arc, multiple circular arc, etc. This approach has the virtue of employing airfoil sections about which something is usually known with respect to losses, deviation angle, and operating limits. Reference 1, an earlier publication of this laboratory, is representative of this approach.

A typical contemporary design will be accomplished using a streamline curvature or matrix through-flow analysis incorporating computing stations internal to blade rows as well as at blade edges and in free spaces. Some criterion for optimization of blade shape must be chosen. (The authors of this report choose to achieve a particular shape of static pressure distribution along streamlines.) The spanwise distributions of inlet and outlet relative flow angles, loss coefficients, etc. will have been determined through some preliminary design procedure. A rule for determining deviation angle and distributing it along streamlines will have been selected. Subsequently, the aerodynamic blade design procedure consists of assuming a blade geometry, performing an aerodynamic analysis using specified relative flow angles as input data, and then repeating this procedure as many times as necessary, varying the parameters describing the airfoil sections, until the result of the aerodynamic analysis adequately satisfies the chosen optimization criterion.

There are three principal disadvantages to employing this procedure for the design of transonic and supersonic blade rows. First, the iteration required is time consuming and, to some degree, laborious. Many adjustments to the geometry specified may be required before optimization objectives are met. Although the bulk of the calculations are performed by computer, the designer generally must still examine and evaluate the aerodynamic result and decide what to change, and how much, for the next attempt. Second, when airfoil shape is restricted to any particular class of airfoil, it will rarely be possible to achieve the optimization objectives as closely as might be desired, everywhere along the span. Some compromise will nearly always be necessary. Third, streamline curvature and matrix through-flow analyses sometimes experience difficulty in finding solutions for certain combinations of high relative Mach number and high absolute Mach number near choking when relative flow

angle is specified as input data within blade rows. This is a numerical problem related to the construction of these computer programs and can vary considerably from one program to another.

A design method which eliminates or appreciably reduces these problems consists of specifying total temperature (in rotors) or the product of radius and whirl velocity (in stators) as input data to the aerodynamic analysis program and then fitting airfoils of arbitrary shape to the resulting relative flow angles. In so doing, one loses the data base which might be associated with a particular class of airfoil, but the value of such a geometrically-related data base is questionable for transonic and supersonic sections. Following this approach, the aerodynamic analysis can be optimized with considerably fewer iterations than are usually required with specified geometry. In most cases, optimization objectives can be achieved on nearly every streamsurface. Some interaction is required between the blade design program and the aerodynamic analysis to insure that the blade lean angles and blockages are kept up-to-date. However, the over-all effort required to achieve a satisfactory design using this method has been found to be substantially less.

The principal difficulty in developing a procedure to define arbitrary airfoils consists of arriving at a method which produces aerodynamically attractive shapes which are in addition practical from a structural and manufacturing viewpoint. This report describes one such method developed at the Aerospace Research Laboratories. The method has been incorporated into a computer program which is an extension of the work reported in Reference 1. In addition to determining the shape of the airfoils on aerodynamic surfaces, section properties are computed, the blade is stacked, and Cartesian coordinates are determined for manufacturing purposes.

The overall design technique is described in Section II. The mathematical details of implementing the technique in a calculation procedure are described in Sections III and IV. A method of producing the optimal camber line on a streamsurface is treated in Section III; the calculations related to other aspects of the blade design procedure are discussed briefly in Section IV. Sections V, VI, and VII present the details of and use of a computer program which incorporates this design technique, currently used at the Aerospace Research Laboratories in the design of axial compressor airfoils.

SECTION II

DESCRIPTION OF THE TECHNIQUE

1. TECHNIQUE OVERVIEW

The technique described in this report uses an iterative procedure to produce an "optimal" camber line on each streamsurface. A thickness destribution is applied to each camber line, and the resulting blade elements are stacked to produce the desired airfoil. The technique requires the designer to specify the incidence distribution radially at the blade leading edge, the location of the stack axis and the stacking offsets of each streamsurface section centroid therefrom, the parameters of the thickness distribution, and the chordwise distribution of deviation angle along the span.

The optimization criterion which has been selected for the section camber line is to maximize the absolute value of the minimum radius of curvature on the camber line. The "optimal" camber line is chosen from a set of camber lines containing the minimum number of inflection points. This original set of camber lines is generated by varying the second derivative at the leading edge.

The starting point of the design technique is output data from an aerodynamic analysis of a particular blade row which has been generated by specifying a parameter other than blade geometry, such as those suggested in the Introduction, across the blade row. This data is in the form of the meridional coordinates of the streamsurfaces and the chordwise distribution of the relative air angles on each streamsurface. The essential steps of the technique itself are described in a qualitative sense in the remainder of this section.

2. DETAILS OF THE TECHNIQUE

The first step of the overall procedure is to determine the optimal blade section on each streamsurface. This in itself is a multiple-step process which incorporates an iteration with solidity to establish a camber line for each of a range of values of the second derivative at the leading edge, a search procedure to choose the "optimal" camber line, and the application of a thickness distribution to this camber line.

The procedure begins with an initial estimate of solidity on the streamsurface. This estimate is made by applying the stagger angle, assumed equal to the average of the inlet and outlet relative air angles, to the meridional chord length, obtained by integrating along each streamline from the assumed

leading to trailing edge, to get a first estimate of the true chord. The solidity is then computed from this estimate, the mean streamsurface radius, and the number of blades in the blade row.

The total deviation angle is computed from this estimate in some fashion, such as the modified Carter's Rule with appropriate constants. The deviation angle at each internal point is next determined as a designer-specified fraction of the total deviation. The required section angle at each internal point and at the trailing edge is then the difference between the relative air angle and the deviation angle, while the section angle at the leading edge is the difference between the relative air angle and the incidence angle.

Each section camber line is determined by fitting a segment of a smooth curve, such as a cubic, between each pair of points from the leading to the trailing edge of the section. The slope at the endpoint of each segment matches the specified section angle there. The true chord length and the associated value of solidity can then be determined. If the solidity differs by more than a prescribed tolerance from the previous estimate, the steps subsequent to and including the total deviation determination are repeated for the revised values of solidity until the desired tolerance is achieved.

The entire procedure described thus far is repeated for a range of values of the second derivative at the leading edge. The resultant set of camber lines are inspected first to focus only on those which contain the minimum number of inflection points, and from these to choose the camber line which is "optimal" in the sense previously described.

A thickness distribution is then applied to this camber line, and the procedure is repeated for each streamsurface. The blade sections are stacked, and the Cartesian coordinates of the resulting blade determined. In addition, the blade blockage and lean angle are computed at each appropriate streamsurface-computing station intersection point.

As a final step, the designer inspects the resulting blockages, Cartesian centroid offsets, blade lean angles, and coincidence of the blade edges with the designated computing stations. If necessary, appropriate changes are made in the inputs to the aerodynamic analysis, and the entire procedure recycled until adequate overall coincidence between the blade design and the aerodynamic analysis is achieved.

SECTION III

THE SECTION CAMBER LINE

The first item required in the application of the technique described in the preceding section is the meridional chord length of the blade element, obtained by integrating along the streamline between the assumed leading and trailing edges. This is accomplished by passing a spline curve through the meridional coordinates (x, r) of the streamsurface. The slope of the streamsurface is calculated (as the slope of the spline-curve) at 100 points distributed uniformly on the x-axis (axially) between the edges of the blade section. The chord length, C_m, is obtained from the equation

$$C_m = \sum_{n=2}^{100} (x_n - x_{n-1}) \sqrt{1 + \left[\left(\frac{dr}{dx_n} + \frac{dr}{dx_{n-1}}\right)\Big/2\right]^2} \qquad (1)$$

An estimate of true chord is obtained by applying the stagger angle, assumed equal to the average of the inlet and outlet relative air angles, to the meridional chord so that the true chord estimate, C_e, is

$$C_e = \frac{C_m}{\cos\left(\frac{\beta_{\ell e} + \beta_{te}}{2}\right)} \qquad (2)$$

The first estimate of solidity may be computed from the equation

$$\sigma = \frac{NC_e}{2\pi\left(\frac{r_{\ell e} + r_{te}}{2}\right)} \qquad (3)$$

where N is the number of blades and $r_{\ell e}$, r_{te} are the radii of the streamsurface at the leading and trailing edges, respectively.

The calculation of the deviation angle, δ, follows the NASA method (Reference 2, Equations 269 and 271) with an additional term, γ.

$$\delta = \delta_{0_{10}} K_{\delta_s} K_{\delta_t} + \frac{m}{\sigma^b} (\beta_{\ell e} - i - \beta_{te} + \delta) + \gamma \tag{4}$$

where $\delta_{0_{10}}$ is the variation from the reference deviation for a 10 percent-thick NACA 65-series thickness distribution

K_{δ_s} is a correction factor for a blade shape with a thickness distribution different from a 65-series blade

K_{δ_t} is a correction factor for a maximum thickness other than 10 percent

m is the slope of the deviation angle variation from reference deviation with camber

b is the solidity exponent (variable with air inlet angle)

β_{xe} is the relative air angle at the particular edge

i is the incidence angle

γ is the arbitrary extra deviation

Solving Eq (4) for δ yields

$$\delta = \frac{\delta_{0_{10}} K_{\delta_s} K_{\delta_t} + \frac{m}{\sigma^b} (\beta_{\ell e} - i - \beta_{te}) + \gamma}{\left(1 - \frac{m}{\sigma^b}\right)} \tag{5}$$

For use in the calculation procedure, K_{δ_s}, i, and γ are specified by the designer. Several of the other quantities are obtained from known quantities and figures of Reference 2: $\delta_{0_{10}}$ from Figure 161; K_{δ_t}, Figure 172; m, Figure 166; and b, Figure 164.

The blade angle, α, is established at several points across the blade element from the relative air angle, β, modified by the proper consideration of incidence or deviation. At the leading edge,

$$\alpha_{\ell e} = \beta_{\ell e} - i \tag{6}$$

and at the trailing edge,

$$\alpha_{te} = \beta_{te} - \delta \tag{7}$$

At the other points, the blade angles are determined by subtracting a fraction f of the trailing-edge deviation from the relative air angle. At each internal point j,

$$\alpha_j = \beta_j - f_j\delta \tag{8}$$

The fraction f_j is determined by radial interpolation from the deviation distributions specified by the designer.

The camber line is constructed by fitting a third order polynomial (cubic) through each pair of points from the leading to the trailing edge of the section. Thus, each segment of the camber line is defined by equations of the form

$$y = ax^3 + bx^2 + cx + d \tag{9}$$

$$y' = 3ax^2 + 2bx + c \tag{10}$$

$$y'' = 6ax + 2b \tag{11}$$

As a result, each segment has at most one inflection point ($y'' = 0$) in its useful range, and in most instances has none.

The constants a, b, c, and d for any particular segment can be expressed in terms of the endpoints (denoted by subscripts 1 and 2) of that segment as

$$a = \frac{(y_2'-y_1') - y_1''(x_2-x_1)}{3\left[(x_2^2-x_1^2) - 2x_1(x_2-x_1)\right]} \tag{12}$$

$$b = \frac{y_1'' - 6ax_1}{2} \tag{13}$$

$$c = y_1' - 3ax_1^2 - 2bx_1 \tag{14}$$

$$d = y_1 - ax_1^3 - bx_1^2 - cx_1 \tag{15}$$

For simplicity, the leading edge of the camber line is placed at the origin of the coordinate system, resulting in the following boundary conditions for the first segment:

$$\begin{aligned} \text{At } x = 0,\ y &= 0 \\ y' &= \tan \alpha_{\ell e} \\ y'' &= y_o'' \end{aligned} \tag{16}$$

$$\text{At } x = x_1,\ y' = \tan \alpha_1 \tag{17}$$

With these boundary conditions, the appropriate values of a, b, c, and d for this segment are completely determined.

The boundary conditions for the second and subsequent segments are specified at one endpoint by equating the first and second derivatives to the values for the preceding segment at the point of juncture; for example, for the second segment,

$$\begin{aligned} \text{At } x = x_1,\ y &= y_{1\,(\text{first segment})} \\ y' &= \tan \alpha_1 \\ y'' &= y''_{1\,(\text{first segment})} \end{aligned} \tag{18}$$

and at the other endpoint,

$$\text{At } x = x_2,\ y' = \tan \alpha_2 \qquad (19)$$

From these conditions, a distinct set of constants (a, b, c, d) are computed for the second segment. This same procedure is applied to each pair of points to produce a camber line with continuous first and second derivatives all along its length.

Note that the first segment of the camber line requires the specification of the second derivative y_o'' at the leading edge. This boundary condition affects the constants of the first segment and thus the nature of this entire segment, including the conditions (y_1, y_1'') at the other endpoint. Since the constants for the second segment are established from these conditions, and so on for the rest of the segments, the nature of the entire camber line depends on the value of y_o'' specified at the leading edge.

It has been found convenient to specify y_o'' in terms of a non-dimensional parameter S/R_o, the ratio of blade spacing, S, to the radius of curvature, R_o, at the leading edge. R_o is given by the equation

$$R_o = \frac{\left[1 + \tan^2 \alpha_{\ell e}\right]^{3/2}}{y_o''} \qquad (20)$$

and S is obtained from

$$S = \frac{2\pi r_{\ell e}}{N} \qquad (21)$$

From Equations (20) and (21),

$$\frac{S}{R_o} = \frac{2\pi r_{\ell e}\, y_o''}{N\left[1 + \tan^2 \alpha_{\ell e}\right]^{3/2}} \qquad (22)$$

Solving for y_o'' gives

$$y_o'' = \frac{N\left[1 + \tan^2 \alpha_{\ell e}\right]^{3/2}}{2\pi r_{\ell e}} \cdot \frac{S}{R_o} \tag{23}$$

which indicates that y_o'' is the parameter S/R_o multiplied by a constant.

For a particular value of S/R_o, the true chord length of the resulting camber lines may be determined from the endpoint of the final segment as

$$C = \sqrt{(x_{te})^2 + (y_{te})^2} \tag{24}$$

This value is used to compute a revised value of solidity, which is compared to the original estimate. If satisfactory coincidence has not been achieved, a corrected deviation angle is computed from the revised solidity, and the camber line reconstructed. This iteration is repeated until adequate coincidence has been obtained.

It is difficult if not impossible to have an intuitive notion of a "good" value of y_o'' (hence, S/R_o). For some ranges of S/R_o, each camber line segment may contain an inflection point, while for other ranges, few if any segments may contain such a point. The authors of this report have assumed that, for aerodynamic as well as mechanical reasons, the most desirable airfoil among several matching the same flow angle at each computing station will be one having the minimum number of inflection points between leading and trailing edge. This is accomplished by calculating the camber line for a broad range of values of S/R_o and isolating the range in which the minimum total number of inflection points occurs. This range is examined with finer S/R_o increments to generate a new set of camber lines on which the minimum absolute radius of curvature is identified. The value of S/R_o which produces the largest such radius is then made the mid-value of S/R_o for the final search pass, using still finer S/R_o increments. The camber line which possesses the largest value of the minimum radius of curvature at the conclusion of this search procedure is chosen as opt?

SECTION IV

OTHER ASPECTS OF THE CALCULATION PROCEDURE

Various other aspects of the calculation procedure are discussed briefly in this section. For greater detail on these topics, the reader's attention is directed to Reference 1, where these items are treated at some length as elements of the calculation procedure of which the subject procedure is a modification.

1. THE SECTION THICKNESS DISTRIBUTION

The thickness distribution which is applied to the camber line herein described is that referred to as the "Standard Thickness Distribution" in Reference 1. The distribution is defined by two third-order polynomials, one from the leading edge to the point of maximum thickness, and another from there to the trailing edge. At the point of juncture, the thickness and the first and second derivatives of thickness are equated. In order to prevent a reflex curvature from occurring in the thickness distribution near the leading edge, the second derivative of thickness is set equal to zero at the leading edge. The thickness of the leading and trailing edges is independently specified so that it need not be the same at both edges. At the leading edge, the blade surface is completed with a circular arc. At the trailing edge, the blade surface is truncated by connecting the two endpoints with a straight line.

2. CARTESIAN COORDINATES FOR THE BLADE

The preceding material has described the methods used to design individual blade sections. When located as desired relative to the blade stacking axis, the section coordinates are the coordinates of the streamsurface blade section. A series of sections on all streamsurfaces specifies the envelope of the blade, but the surface coordinates are not in a form convenient for manufacturing purposes. The calculation procedure uses a spline-curve to interpolate (or extrapolate) the coordinates of the blade surfaces for manufacturing purposes.

3. SECTION PROPERTIES

The stacking axis of the blade is passed through each streamsurface section either at one of the edges or at a point specified relative to the centroid of the section. Because the streamsurface sections are in general non-planar, the centroids of the manufacturing sections will not generally lie precisely

on the stacking axis when the streamsurface sections are stacked on their centroids. By determining the locations of the centroids of the manufacturing sections so obtained, it is possible to estimate the offsets that must be applied when restacking the streamsurface sections to locate the manufacturing centroids as desired relative to the stacking axis.

To assist further in the mechanical analysis of the blade, the areas, second moments of area, principal axes, and principal second moments of area for both the streamsurface and manufacturing sections are also determined in the calculation procedure.

4. BLADE CHARACTERISTICS

A calculation of the volume enclosed by the blade between the innermost and outermost streamsurfaces is made. In addition, quantities which describe the blade on cylindrical surfaces and which may be required in an aerodynamic analysis of the blade are computed as an option. The calculations are presented here because a typographical error undetected during editing of Reference 1 has impaired their usefulness in that Reference.

First, the angular position of the camber line with respect to the stack axis at a streamsurface-computing station intersection is specified in terms of Φ, defined in Figure 1.

The physical passage blockage (B) due to the presence of the blades is determined as a percentage of the passage circumference in terms of the number of blades in the blade row and τ, the angle subtended on the cylindrical surface by each blade:

$$B = \frac{N\tau}{2\pi} \tag{25}$$

The blade lean angle, ϵ, with respect to the radial direction at a given point is obtained from the slope of a spline-curve fit through the y-z Cartesian coordinates of the streamsurface section camber lines at the particular axial location.

Thus

$$\epsilon = \Phi - \text{Arctan}\left(\frac{dy}{dz}\right) \tag{26}$$

Two other quantities are needed to produce the proper mean-camber line angle on the cylindrical surface: The local computing station inclination, μ, obtained from the specified station description; and the local streamsurface inclination, γ, obtained from the specified x-r streamsurface description. Together with the camber line angle on the streamsurface, α_*, these quantities are employed in the following equation to calculate the proper cylindrical-surface section angle, α_*°:

$$\tan \alpha_*^\circ = \frac{\tan \gamma \tan \epsilon + \tan \alpha_*/\cos \gamma}{1 - \tan \mu \tan \gamma} \qquad (27)$$

SECTION V

USE OF THE PROGRAM

Basic information required by the user to run the ARL computer program which incorporates the calculation procedure described in this report is given in this section. The various input data items are defined first, and the input data format is then specified. A description of the output data that may be expected is given. (Implementation of the program on a computing system is not discussed here, but in the section entitled "Computer Program Details".)

1. DEFINITION OF INPUT DATA ITEMS

TITLE — An alphanumeric title of 72 characters that may be used to identify a run.

NLINES — The number of streamsurfaces which are defined and on which blade sections will be designed. Must satisfy $2 \leq \text{NLINES} \leq 15$.

NSTNS — The number of computing stations at which the streamsurface radii are specified. Must satisfy $3 \leq \text{NSTNS} \leq 10$.

NZ — The number of constant-z planes on which manufacturing (Cartesian) coordinates for the blade are required. Must satisfy $3 \leq \text{NZ} \leq 15$.

NSPEC — The number of radially-disposed points at which the parameters of the blade sections are specified. Must satisfy $1 \leq \text{NSPEC} \leq 15$.

ISEGPT — The number of points to be used to define each segment of the camber line. $2 \leq \text{ISEGPT} \leq \text{Integer}\left(\frac{80}{\text{IRTE-IRLE}}\right)$

NBLADE — The number of blades in the blade row.

ISTAK — If ISTAK = 0, the blade will be stacked at the leading edge.

If ISTAK = 1, the blade will be stacked at the trailing edge.

If ISTAK = 2, the blade will be stacked at, or offset from, the section centroid.

IPUNCH	If IPUNCH = 0, the quantities necessary for aerodynamic analysis of the resulting blade are not produced on punched cards. If IPUNCH = 1, these quantities are produced on punched cards.
IFPLOT	Where CALCOMP software is incorporated into the computing system, IFPLOT specifies the creation of precision plots. (Further information regarding the requirements for this are given in the section entitled "Computer Program Details.") If IFPLOT = 0, no plots will be produced. If IFPLOT = 1, a plot of the streamsurface sections will be produced. All NLINES sections are shown superimposed. The origin for each section plot is offset from the centroid of the section by distances specified by DELX and DELY. If IFPLOT = 2, a plot of the manufacturing sections will be produced. The origin is the blade stacking axis, and all NZ sections are shown superimposed. If IFPLOT = 3, both of the plots described for IFPLOT = 1 and 2 will be produced. If IFPLOT = 4, individual plots of each of the manufacturing sections will be produced. The axes are rotated clockwise by the section stagger angle for each plot.
IPRINT	The input data is always listed by the program. Details of the streamsurface and manufacturing sections are printed as prescribed by IPRINT. If IPRINT = 0, details of streamsurface and manufacturing sections are printed. If IPRINT = 1, details of streamsurface sections are printed. If IPRINT = 2, details of the manufacturing sections are printed.
ZINNER, ZOUTER	The NZ manufacturing sections are equispaced between z equals ZINNER and ZOUTER.
SCALE	When precision plots are produced, SCALE is the scale factor employed.

STACKX — The axial coordinate of the stacking axis for the blade, relative to the same origin as used for the station locations, XSTA.

PLTSZE — The size (inches) of the plotter to be used in the creation of precision plots.

IRLE — The number of the computing station designated as the blade leading edge.

IRTE — The number of the computing station designated as the blade trailing edge.

NRADEV — The number of radii at which the non-dimensional deviation distribution is specified. $1 \leq NRADEV \leq 5$.

NINC — The number of points which describe the incidence angle distribution. $1 \leq NINC \leq 15$.

NSIGN — An integer which specifies the sign convention of the particular blade. Conventionally positive rotors and stators have NSIGN values of -1 and +1, respectively.

IFCA — If IFCA = 1, the factor m in the deviation angle rule is that of the NACA-65-series mean line (Figure 195, Reference 2).

If IFCA = 2, the factor m in the deviation angle rule is that of the circular-arc mean line.

IPASS — The number of initial values of S/R_o which are to be used in the procedure to find the optimal camber line. $20 \leq IPASS \leq 50$.

XKSHPE — The shape factor (K_{δ_s}) in the deviation equation.

SOLTOL — The solidity tolerance used in the iterative procedure to produce a consistent camber line.

NPTS — The number of points defining a particular chordwise deviation distribution. $1 \leq NPTS \leq 10$.

RADEV — Radius at which a particular deviation distribution applies.

SM — An array of NPTS meridional chord fractions which, together with DEVCRV, specify a particular deviation distribution.

DEVCRV — An array of NPTS normalized deviation fractions which, together with SM, specify a particular deviation distribution.

RINC	An array of NINC radii which, together with XINC, specify the incidence distribution at the leading edge.
XINC	An array of NINC incidence angles which, together with RINC, specify the incidence distribution. Input positive for conventionally positive rotors and stators (see NSIGN).
DELDEV	An array of NINC angles which, together with RINC, specify the distribution of the "arbitrary extra deviation" term in the deviation determination. Input positive for conventionally positive rotors and stators (see NSIGN).
KPTS	The number of points provided to specify the shape of a computing station. If KPTS = 1, the computing station is upright and linear. If KPTS = 2, the computing station is linear and either upright or inclined. If KPTS > 2, a spline curve is fitted through the points provided to specify the shape of the station.
IFANGS	If IFANGS = 0, the calculations of the quantities required for aerodynamic analysis will be omitted at a particular computing station. If IFANGS = 1, these calculations will be performed at that station.
XSTA	An array of KPTS axial coordinates (relative to an arbitrary origin) which, together with RSTA, specify the shape of a particular computing station.
RSTA	An array of KPTS radii which, together with XSTA, specify the shape of a particular computing station.
R	The streamsurface radii at NLINES locations at each of the NSTNS stations.
AIRANG	The relative air angles at NLINES locations at each of the NSTNS stations.

ZR	The variation of properties of the streamsurface blade sections is specified as a function of streamsurface number. The various quantities are then interpolated (or extrapolated) at each streamsurface. The streamsurfaces are numbered consecutively from the innermost outward, starting with 1.0. ZR must increase monotonically, there being NSPEC values in all.
YA	The fraction of meridional chord used as the leading edge in the calculation of the section chord for the solidity iteration on a particular streamsurface. If YA = 0., the true chord length is calculated. $0.0 \leq YA \leq 1.0$.
YB	The increment in S/R_o which, with SDIVR and IPASS, establishes the initial range of S/R_o which is inspected in the determination of the optimal camber line on a particular streamsurface. May be positive or negative.
YC	If YC = 0., the radius of curvature at the leading edge of each camber line will be considered in the procedure to identify the camber line which maximizes the minimum radius of curvature. If YC = 1.0, the radius of curvature at the leading edge will not be considered in this procedure.
YE	The maximum number of inflection points expected on a particular camber line. If the calculated minimum number is greater than YE, an informational diagnostic is printed.
RLE	The ratio of section leading edge radius to chord.
TC	The ratio of section maximum thickness to chord.
TE	The ratio of section trailing edge half-thickness to chord.
Z	The location of the section maximum thickness, as a fraction of camber line length.
SDIVR	The initial value of S/R_o.
DELX, DELY	The stacking axis passes through the streamsurface blade sections, offset from the centroid, leading, or trailing edge by DELX and DELY in the x and y directions, respectively.

2. INPUT DATA FORMAT

Data input is by punched card, and three formats are used. The first card only is alphanumeric, using the first 72 columns of the card. Integers are placed in three-column fields, which start with Column 1. No decimal points are used, and the integer should be right-justified. Real numbers are placed in 12-column fields, which also start with Column 1. Decimal points should be included, and the numbers may be placed anywhere in the field.

In the following chart, one line corresponds to one card.

```
TITLE

NLINES NSTNS NZ NSPEC ISEGPT NBLADE ISTAK IPUNCH IFPLOT IPRINT

ZINNER ZOUTER SCALE STACKX PLTSZE

IRLE IRTE NRADEV NINC NSIGN IFCA IPASS

XKSHPE SOLTOL

NPTS                                 )
                                     )
RADEV                                } repeated NRADEV times
                                     )
SM DEVCRV } repeated NPTS times      )

RINC XINC DELDEV } repeated NINC times

KPTS IFANGS                           )
                                      )
XSTA RSTA } repeated KPTS times       } repeated NSTNS times
                                      )
R AIRANG } repeated NLINES times      )

ZR YA YB YC YE RLE          )
                            } repeated NSPEC times
TC TE Z SDIVR DELX DELY     )
```

Listing of a sample input data deck is included under "Example of Use of the Program."

3. OUTPUT DATA

Printed output from the program may be considered to consist of four sections: a printout of the input data, details of the camber line and blade section on each streamsurface, a

listing of quantities required for aerodynamic analysis, and details of the manufacturing sections determined on the constant-z planes. These are briefly described below.

The input data printout includes all quantities read in, and is self-explanatory.

Details of the streamsurface blade sections are printed if IPRINT = 0 or 1. Listed first are the results of the investigations of the S/R_o parameter. The initial table presents the results of the first iteration which is used to identify the range of S/R_o in which the minimum number of inflection points occur on the camber line. This range is in turn investigated with finer increments of S/R_o to determine the maximum value of the minimum radius of curvature. Then follow the details of the optimal camber line which has been identified by a third investigation of S/R_o with still finer parameter increments. These details include the deviation and solidity which have been calculated for this optimal S/R_o, and a description of the camber line in terms of coordinates, first and second derivatives, and the radii of curvature. Listed next are the parameters defining the blade section, some of which are computed and some of which are interpolated at the streamsurface from the tables read in. Then follow details of the blade section in "normalized" form. The blade section geometry is given for the particular section, except that the meridional projection of the chord is unity. For this section of the output, the coordinate origin is the blade leading edge. The following quantities are given: blade chord, stagger angle, camber angle, section area, location of centroid of the section, second moments of area of the section about the centroid, orientation of the principal axes, and the principal second moments of area of the section about the centroid. Then are listed the coordinates of the camber line, the camber line angle, the section thickness, and the coordinates of the blade surfaces. A line-printer plot of the normalized section follows. The scales for the plot are arranged so that the section just fills the page. Thus, the scales will generally differ from one plot to another. "Dimensional" details of the blade section are given next. The normalized data given previously is scaled to give the proper blade section. For this section of the output, the coordinates are with respect to the blade stacking axis. The following quantities are given: blade chord, radius and location of center of the leading edge, section area, the second moments of area of the section about the centroid, and the principal second moments of area of the section about the centroid. The coordinates of points on the blade surfaces are then listed, followed by the coordinates of 31 points distributed at six degree intervals around the leading edge. Finally, the coordinates of the blade surfaces and points around the leading edge are shown in Cartesian form.

The quantities required for aerodynamic analysis are printed at all computing stations specified by the IFANGS parameter. The radius, section angle, blade lean angle, blade blockage, and relative angular location of the camber line are printed at each streamsurface intersection with the particular computing station.

Details of the manufacturing sections are printed if IPRINT = 0 or 2. At each value of z specified by ZINNER, ZOUTER and NZ, section properties and coordinates are given. The origin for the coordinates is the blade stacking axis. The following quantities are given: section area, the location of the centroid of the section, the second moments of area of the section about the centroid, the principal second moments of area of the section about the centroid, the orientation of the principal axes, and the section torsional constant. Then the coordinates of points on the blade section surfaces are listed, followed by 31 points around the leading edge.

Precision plots are produced if IFPLOT = 1, 2, 3 or 4 as described under the definition of IFPLOT given previously.

If IPUNCH = 1, the program punches the quantities required for aerodynamic analysis, together with identifying indices denoting station number and streamsurface number, on cards in the following format: 5 fields each of 12 locations for the quantities themselves, followed by 2 fields each of 3 locations for the indices.

SECTION VI

EXAMPLE OF USE OF THE PROGRAM

This section shows the use of the program to generate a compressor rotor with an inlet hub-to-tip ratio of 0.31, a rather steep hub ramp angle (32.5°), and a constant outer radius. The blade is defined by six computing stations, one at either edge and four internal. This results in a camber line composed of five segments. Six streamlines have been used to define the flow and hence the blade by means of the streamsurface blade sections. The computing-stations and streamsurfaces which define the blade are depicted in a stack-axis projection in Figure 2.

1. INPUT DATA

The input data deck used for this example is listed below. Some points of interest are noted in the order in which they occur in the input.

As mentioned above, six streamsurface blade sections are used to define the blade. The streamsurface radii are specified at eight computing stations, the first and last of which are outside of the rotor. This ensures that the boundary conditions imposed on the spline-curve (zero curvature at the endpoints) have little influence on the shape of the curve representing the streamsurface within the blade. The useful relative air angles are specified at the six computing stations defining the blade. The computing stations within the blade are curved in an attempt to make the meridional projections of the camber line segments approximately equal. The parameters which define the streamsurface blade sections are given at six locations; that is, at every streamsurface. Twelve points are used to define each segment, which results in a camber line defined by a total of fifty-six points. (This number serves the purposes of this example well, but it would be advantageous to use more points if the precision-plot output is to be incorporated directly in the manufacturing procedure.) There are twenty blades in the particular blade row, stacked approximately on their streamsurface centroids. No punched output is requested. All optional sections of the printed output are to be printed, and superimposed section plots are to be produced on a plotter (with an 11-inch useful range) at two and one-half times full size.

Stations 2 and 7 are the leading and trailing edges of the blade, respectively. The deviation distribution is the same at all radii, since it is specified only at one radius. The incidence angles and the arbitrary extra deviation are specified

at six points for this rotor blade. The factor m in the deviation calculation is to be that of a circular-arc camber line. Thirty camber lines will initially be investigated in the effort to identify the optimal camber line, representing a broad range of the S/R_o parameter. The shape factor in the deviation calculation is unity, and the tolerance on solidity in the iteration for each camber line is 0.005.

The streamsurface radii and relative air angles have been determined from an aerodynamic analysis of the flow through the blade row. The leading edge of the blade has been established as the point from which the chord length, and thus the solidity, will be computed.

The increment in the S/R_o parameter has been initially set equal to + 0.04 in the investigation to find the optimal camber line. This increment will automatically be reduced twice subsequently as the most favorable range of S/R_o is more closely scrutinized. It is anticipated that no inflection points will be required near the hub, while a single inflection point will probably be required in the mid and tip regions of the blade. The blade thickness distribution is determined by aerodynamic and mechanical factors. The leading edge radius and trailing edge half-thickness are set to approximately 0.005 inch, probably a practical minimum. Maximum thickness/chord ratios vary from 6 percent at the hub to 2.5 percent at the casing. The maximum thickness is placed in the rearward portion of the camber line, which helps to maintain a small leading edge wedge angle.

```
    EXAMPLE - LOW HUB/TIP RATIO COMPRESSOR ROTOR DESIGN
  6  8  7  6 12 20  2  0  3  0
2.5          8.50         2.5          -7.05        11.0
  2  7  1  6 -1  2 30
1.           .005
  6
3.3
0.           .1
0.2          .11
0.4          .15
.6           .22
.8           .38
1.           1.00
2.68         6.37         2.
3.84         5.57         2.
5.09         4.85         2.
6.42         4.2          2.
7.79         3.92         2.
8.5          3.69         2.
  1  0
-9.          2.35
2.35
3.6454
4.9893
6.3617
7.7723
8.5
  5  0
-8.51        2.6514
-8.5926      5.0663
-8.531       6.3989
-8.3115      7.7861
-8.161       8.5
      2.6514    -40.9695
      3.8041    -47.2370
      5.0786    -50.8039
      6.4109    -53.6378
      7.7902    -57.2964
      8.5000    -59.7859
  4  1
-7.905       3.0363
-8.000       5.07
-7.96        6.48
-7.725       8.5
      3.0363    -30.0198
      4.0696    -37.2906
      5.2456    -44.5116
      6.4975    -51.0404
      7.8091    -57.8178
      8.5000    -61.3719
```

```
  4  1
-7.35         3.3893
-7.395        5.385
-7.415        6.565
-7.311        8.5
      3.3893     -20.0393
      4.3344     -28.9282
      5.4194     -38.6681
      6.5824     -47.7054
      7.8307     -56.2706
      8.5000     -60.2293
  4  1
-6.801        3.7385
-6.801        5.49
-6.87         6.65
-6.94         8.5
      3.7385     -12.2698
      4.5798     -21.2618
      5.5662     -33.3334
      6.6591     -44.2126
      7.8459     -54.0832
      8.5000     -58.9884
  4  1
-6.251        4.0884
-6.18         5.7
-6.3          6.725
-6.56         8.5
      4.0884      -5.4451
      4.8259     -13.8107
      5.7147     -27.6798
      6.7242     -40.6966
      7.8575     -51.6465
      8.5000     -57.5196
  5  1
-5.665        4.4612
-5.5846       5.896
-5.7208       6.7945
-5.9516       7.8661
-6.134        8.5
      4.4612      11.5881
      5.0795      -7.0980
      5.8623     -25.6222
      6.7858     -40.0751
      7.8716     -51.3351
      8.5000     -56.5798
  4  0
-5.52         4.5534
-5.35         5.2
-5.3          5.80
-5.7          8.5
```

4.5534					
5.1806					
5.9412					
6.8378					
7.8877					
8.5					
1.0	0.	0.04	0.	0.	.00155
.06	.00155	.56	-0.2	.01	
2.0	0.	.04	0.	0.	.00149
.0525	.00149	.59	-0.15	-.018	
3.0	0.	.04	0.	1.	.00143
.0423	.00143	.62	-0.3	.035	
4.	0.0	.04	0.0	1.0	.00137
.0325	.00137	.65	-1.3	.02	
5.0	0.0	.04	0.	1.0	.00131
.0265	.00131	.68	-2.0	.01	
6.	.0	0.04	0.	1.0	.00125
.025	.00125	.70	-2.3	-.001	

2. OUTPUT DATA

The input data specified all optional output data, and a sample of each segment of the output is presented in this section. A brief description of some aspects of the output is presented below.

Shown first is the printout of the input data. This is followed by details of the first streamsurface blade section. The tables presenting the results of the S/R_Q investigations are followed by a description of the camber line which has been selected. Then appear the details of, and a line-printer plot of, the normalized blade section, followed by the specifications of the section scaled to the proper dimensions. Printed first are the 56 points specified for each blade surface. Next appear the 31 points describing the leading edge radius. The final data for the streamsurface section are the equivalent Cartesian coordinates for these same points.

The format is repeated for each of the remaining streamsurface blade sections, but these results are not reproduced here. Subsequent to the streamsurface data are printed the quantities required for aerodynamic analysis at those stations where requested by the IFANGS parameter.

Details for the seven manufacturing sections defining the blade follow. Reproduced below is the output relating to the first (innermost) section. Properties of the section are followed by coordinates of 56 points on each surface and 31 points around the leading edge. It will be noted that the section centroid is not calculated to be exactly on the stacking axis. If it were desired to have the centroids of the manufacturing sections lie more nearly precisely on the stacking axis, the program would be rerun with either DELX and DELY offsets specified so that they would counteract the mislocation of the centroids previously determined, or with a slightly shifted location of the stack axis. However, the user must bear in mind that the final step in the design procedure is to obtain satisfactory coincidence of the blade with the stations defining its leading and trailing edges in the meridional plane. It is possible that a blade which had all manufacturing sections stacked precisely on their centroids at a particular stacking-axis location would have quite an undesirable meridional profile. There are tradeoffs, then, between the stacking preciseness and the coincidence of the calculated blade's edges with its assumed profile on the one hand, and the number of iterations it would require to find the truly optimal stack location and centroid offsets, on the other.

The input data specified superimposed precision plots of both the streamsurface sections and the manufacturing sections. These plots are reproduced (at reduced size) as Figures 3 and 4,

respectively. It is of interest to refer also to Figure 2. The innermost manufacturing plane is well below the lowest point on the hub streamsurface section in the plane of the stacking axis. The Cartesian coordinates of this streamsurface section show that the lowest point on the section (the 14th point on the leading edge) is at Z = 2.57224. The streamsurface radius at this point is 2.6514, and the innermost manufacturing plane is at Z = 2.5. Thus, at the leading edge, the extrapolation required to define the manufacturing section is somewhat smaller than might first appear. At the trailing edge, extrapolation is required for the first three manufacturing sections. The streamsurface radius at the casing and the Z-coordinate for the outermost manufacturing plane both equal 8.5; however, the Z-coordinates of the blade section are all actually below 8.5. Thus, the outermost section too is defined completely by extrapolation. Of course, portions of the blade that are defined by extrapolation do not appear on the final blade, but facilitate manufacture.

```
                      USAF - ARL(LF) ARBITRARY CAMBER LINE PROGRAM
                      ********************************************

TITLE                          =   EXAMPLE - LOW HUB/TIP RATIO COMPRESSOR ROTOR DESIGN
NUMBER OF STREAMSURFACES       =  6
NUMBER OF STATIONS             =  8
NUMBER OF CONSTANT-Z PLANES    =  7
NUMBER OF BLADE DATA POINTS    =  6
NUMBER OF POINTS PER SEGMENT   = 12
NUMBER OF BLADES IN BLADE ROW  = 20
ISTAK                          =  2
IPUNCH                         =  0
IFPLOT                         =  3
IPRINT                         =  0

ZINNER                         =  2.5000
ZOUTER                         =  8.5000
SCALE                          =  2.5000
STACKX                         = -7.0500
PLTSZE                         = 11.0000

LEADING EDGE STATION NUMBER    =  2
TRAILING EDGE STATION NUMBER   =  7
RADII SPECIFYING DEVIATION     =  1
RADII SPECIFYING INCIDENCE     =  6
SENSE OF ROTATION INDICATOR    = -1
DEVIATION CALCULATION INDEX    =  2
NUMBER OF INITIAL S/R TRIALS   = 30

SHAPE FACTOR                   =  1.0000
SOLIDITY TOLERANCE             =   .0050

DEVIATION CURVE  1     NUMBER OF POINTS = 6     RADIUS =  3.3000

     POINT     NORMALIZED MERIDIONAL     NORMALIZED DEVIATION
                       CHORD                 DISTRIBUTION

       1              0.0000                    .1000
       2               .2000                    .1100
       3               .4000                    .1500
       4               .6000                    .2200
       5               .8000                    .3800
       6              1.0000                   1.0000

INCIDENCE AND EXTRA DEVIATION DISTRIBUTION

     INLET RADIUS    INCIDENCE    EXTRA DEVIATION

        2.6800         6.370          2.000
        3.8400         5.570          2.000
        5.0900         4.850          2.000
        6.4200         4.200          2.000
        7.7900         3.920          2.000
        8.5000         3.690          2.000
```

STREAMSURFACE GEOMETRY SPECIFICATION

COMPUTING STATION 1   NUMBER OF DESCRIBING POINTS= 2   IFANGS(1)= 0

DESCRIPTION X	R	STREAMLINE NUMBER	RADII	AIR ANGLE
-9.0000	2.3500	1	2.3500	-0.0000
-9.0000	3.3500	2	3.6454	-0.0000
		3	4.9893	-0.0000
		4	6.3617	-0.0000
		5	7.7723	-0.0000
		6	8.5000	-0.0000

COMPUTING STATION 2   NUMBER OF DESCRIBING POINTS= 5   IFANGS(2)= 0

DESCRIPTION X	R	STREAMLINE NUMBER	RADII	AIR ANGLE
-8.5100	2.6514	1	2.6514	-40.9695
-0.5926	5.0663	2	3.8041	-47.2370
-8.5310	6.3989	3	5.0786	-50.8039
-8.3115	7.7861	4	6.4109	-53.6378
-8.1610	8.5000	5	7.7902	-57.2964
		6	8.5000	-59.7859

COMPUTING STATION 3   NUMBER OF DESCRIBING POINTS= 4   IFANGS(3)= 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADII	AIR ANGLE
-7.9050	3.0363	1	3.0363	-30.0198
-8.0000	5.0700	2	4.0696	-37.2906
-7.9600	6.4800	3	5.2456	-44.5116
-7.7250	8.5000	4	6.4975	-51.0404
		5	7.8091	-57.8178
		6	8.5000	-61.3719

COMPUTING STATION 4   NUMBER OF DESCRIBING POINTS= 4   IFANGS(4)= 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADII	AIR ANGLE
-7.3500	3.3893	1	3.3893	-20.0393
-7.3950	5.3850	2	4.3344	-28.9262
-7.4150	6.5650	3	5.4154	-38.6681
-7.3110	8.5000	4	6.5624	-47.7054
		5	7.5307	-56.2706
		6	8.5000	-60.2293

COMPUTING STATION 5 NUMBER OF DESCRIBING POINTS= 4 IFANGS(5)= 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADII	AIR ANGLE
-6.8010	3.7385	1	3.7385	-12.2698
-6.8010	5.4900	2	4.5798	-21.2618
-6.8700	6.6500	3	5.5662	-33.3334
-6.9400	8.5000	4	6.6591	-44.2126
		5	7.8459	-54.0832
		6	8.5000	-58.9884

COMPUTING STATION 6 NUMBER OF DESCRIBING POINTS= 4 IFANGS(6)= 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADII	AIR ANGLE
-6.2510	4.0884	1	4.0884	-5.4451
-6.1800	5.7000	2	4.8259	-13.8107
-6.3000	6.7250	3	5.7147	-27.6798
-6.5600	8.5000	4	6.7242	-40.6966
		5	7.8575	-51.6465
		6	8.5000	-57.5196

COMPUTING STATION 7 NUMBER OF DESCRIBING POINTS= 5 IFANGS(7)= 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADII	AIR ANGLE
-5.6650	4.4612	1	4.4612	11.5881
-5.5846	5.8960	2	5.0795	-7.0980
-5.7208	6.7945	3	5.8623	-25.6222
-5.9516	7.8661	4	6.7258	-40.0751
-6.1340	8.5000	5	7.8716	-51.3351
		6	8.5000	-56.5798

COMPUTING STATION 8 NUMBER OF DESCRIBING POINTS= 4 IFANGS(8)= 0

DESCRIPTION X	R	STREAMLINE NUMBER	RADII	AIR ANGLE
-5.5200	4.5534	1	4.5534	-0.0000
-5.3500	5.2000	2	5.1806	-0.0000
-5.3000	5.8000	3	5.9412	-0.0000
-5.7000	8.5000	4	6.8378	-0.0000
		5	7.8677	-0.0000
		6	8.5000	-0.0000

SECTION GEOMETRY SPECIFICATION

STREAMLINE NUMBER	SLD CL FT	IN.DEL S/RC	CONSID LE RC CRV	NO.ALC INFL. PTS	LE RADIUS /CHORD	MAX THICK /CHORD	TE THICK /2*CHORD	POINT OF MAX THICK	START VAL OF S/F	X STACK OFFSET	Y STACK OFFSET
1.00	0.000	.040	0.0000	0.0000	.00155	.06000	.00155	.5600	-.2000	.010000	-0.000000
2.00	0.000	.040	0.0000	0.0000	.00149	.05250	.00149	.5900	-.1500	-.018000	-0.000000
3.00	0.000	.040	0.0000	1.0000	.00143	.04230	.00143	.6200	-.3000	.035000	-0.000000
4.00	0.000	.040	0.0000	1.0000	.00137	.03250	.00137	.6500	-1.3000	.020000	-0.000000
5.00	0.000	.040	0.0000	1.0000	.00131	.02650	.00131	.6800	-2.0000	.010000	-0.000000
6.00	0.000	.040	0.0000	1.0000	.00125	.02500	.00125	.7000	-2.3000	-.001000	-0.000000

STREAMSURFACE 1
ITERATION 1
****

INITIAL S/R = -.2000   INCREMENTAL S/R = .0400

PASS NO.	NO. OF INFLECTION PTS	MIN. RADIUS OF CURVATURE
1	1	.340
2	1	.348
3	1	.357
4	1	.367
5	1	.376
6	1	.387
7	0	.398
8	0	.409
9	0	.421
10	0	.434
11	0	.448
12	0	.463
13	0	.477
14	2	.492
15	2	.505
16	2	.517
17	2	.522
18	2	.521
19	2	.511
20	2	.492
21	4	.472
22	4	.454
23	4	.437
24	4	.421
25	4	.406
26	4	.393
27	4	.380
28	4	.368
29	4	.357
30	4	.346

```
STREAMSURFACE  1
    ITERATION  2
    ************

    INITIAL S/R =    0.0000          INCREMENTAL S/R =    .0110

        PASS NO.     NO. OF INFLECTION PTS     MIN. RADIUS OF CURVATURE

           1                   1                          .387
           2                   0                          .350
           3                   0                          .393
           4                   0                          .396
           5                   0                          .399
           6                   0                          .402
           7                   0                          .405
           8                   0                          .408
           9                   0                          .412
          10                   0                          .415
          11                   0                          .418
          12                   0                          .422
          13                   0                          .425
          14                   0                          .429
          15                   0                          .433
          16                   0                          .436
          17                   0                          .440
          18                   0                          .444
          19                   0                          .448
          20                   0                          .452
          21                   0                          .456
          22                   0                          .460
          23                   0                          .464
          24                   0                          .468
          25                   0                          .472
          26                   0                          .476
          27                   0                          .480
          28                   0                          .484
          29                   2                          .488
          30                   2                          .492

THE MAXIMUM VALUE OF THE MINIMUM RADIUS OF CURVATURE OCCURS AT AN END POINT OF THE PRESENT S/R RANGE
```

OPTIMAL SECTION
****

FINAL S/R = .3025

ITERATIONS ON SOLIDITY

ITERATION 1 DEVIATION = 8.666 SOLIDITY = 3.1200

ITERATION 2 DEVIATION = 8.666 SOLIDITY = 3.1211

POINT	NORMALIZED MERIDIONAL COORDINATE	TANGENTIAL COORDINATE	CAMBER LINE SLOPE	SECOND DERIVATIVE	RADIUS OF CURVATURE
1	0.0000	0.0000	-.6893	.6506	2.754
2	.0193	-.0132	-.6768	.6466	2.723
3	.0387	-.0262	-.6643	.6427	2.692
4	.0580	-.0389	-.6519	.6388	2.663
5	.0773	-.0514	-.6396	.6349	2.635
6	.0967	-.0636	-.6274	.6309	2.607
7	.1160	-.0756	-.6152	.6270	2.581
8	.1353	-.0874	-.6031	.6231	2.556
9	.1547	-.0990	-.5911	.6192	2.532
10	.1740	-.1103	-.5792	.6152	2.508
11	.1933	-.1213	-.5673	.6113	2.486
12	.2127	-.1322	-.5556	.6074	2.465
13	.2304	-.1420	-.5440	.6989	2.111
14	.2481	-.1515	-.5308	.7905	1.836
15	.2659	-.1608	-.5159	.8821	1.615
16	.2836	-.1698	-.4995	.9736	1.435
17	.3013	-.1785	-.4814	1.0652	1.283
18	.3191	-.1868	-.4617	1.1568	1.155
19	.3368	-.1948	-.4404	1.2483	1.045
20	.3545	-.2025	-.4174	1.3399	.950
21	.3723	-.2096	-.3929	1.4314	.866
22	.3900	-.2164	-.3667	1.5230	.793
23	.4077	-.2226	-.3388	1.6146	.729
24	.4253	-.2283	-.3118	1.4680	.783
25	.4428	-.2336	-.2873	1.3214	.852
26	.4604	-.2384	-.2654	1.1749	.943
27	.4779	-.2429	-.2461	1.0283	1.062
28	.4954	-.2471	-.2294	.8817	1.225
29	.5130	-.2510	-.2152	.7351	1.456
30	.5305	-.2546	-.2036	.5886	1.806
31	.5481	-.2561	-.1945	.4420	2.392
32	.5656	-.2615	-.1881	.2954	3.566
33	.5832	-.2647	-.1842	.1489	7.063
34	.6007	-.2680	-.1828	.3023	459.928
35	.6183	-.2712	-.1816	.1369	7.670
36	.6358	-.2743	-.1780	.2715	3.860
37	.6534	-.2774	-.1721	.4061	2.573
38	.6710	-.2804	-.1638	.5407	1.924
39	.6886	-.2832	-.1531	.6753	1.533
40	.7061	-.2857	-.1400	.8099	1.271
41	.7237	-.2881	-.1246	.9445	1.084
42	.7413	-.2901	-.1068	1.0791	.943
43	.7589	-.2918	-.0867	1.2137	.833
44	.7764	-.2931	-.0642	1.3483	.746
45	.7940	-.2940	-.0393	1.4829	.676
46	.8127	-.2945	-.0107	1.5737	.636
47	.8315	-.2944	.0197	1.6644	.601
48	.8502	-.2938	.0517	1.7552	.572

49	.8689	-.2925	.0854	1.8460	.548
50	.8876	-.2906	.1208	1.9368	.528
51	.9064	-.2880	.1579	2.0275	.512
52	.9251	-.2846	.1967	2.1183	.500
53	.9438	-.2806	.2373	2.2091	.491
54	.9625	-.2757	.2795	2.2998	.487
55	.9813	-.2701	.3234	2.3906	.486
56	1.0000	-.2636	.3690	2.4814	.488

STREAMSURFACE GEOMETRY ON STREAMLINE NUMBER 1

```
BETA1          =-34.579     (BLADE INLET ANGLE.)
BETA2          = 20.254     (BLADE OUTLET ANGLE.)
YZERO          =  .00155    (BLADE LEADING EDGE RADIUS AS A FRACTION OF CHORD.)
T              =  .06000    (BLADE MAXIMUM THICKNESS AS A FRACTION OF CHORD.)
YONE           =  .00155    (BLADE TRAILING EDGE HALF-THICKNESS AS A FRACTION OF CHORD.)
Z              =  .5600     (LOCATION OF MAXIMUM THICKNESS AS A FRACTION OF MEAN LINE.)
CORD           = 3.3719     (MERIDIONAL CHORD OF SECTION.)
```

NORMALISED RESULTS - ALL THE FOLLOWING REFER TO ABLADE HAVING A MERIDIONAL CHORD PROJECTION OF UNITY

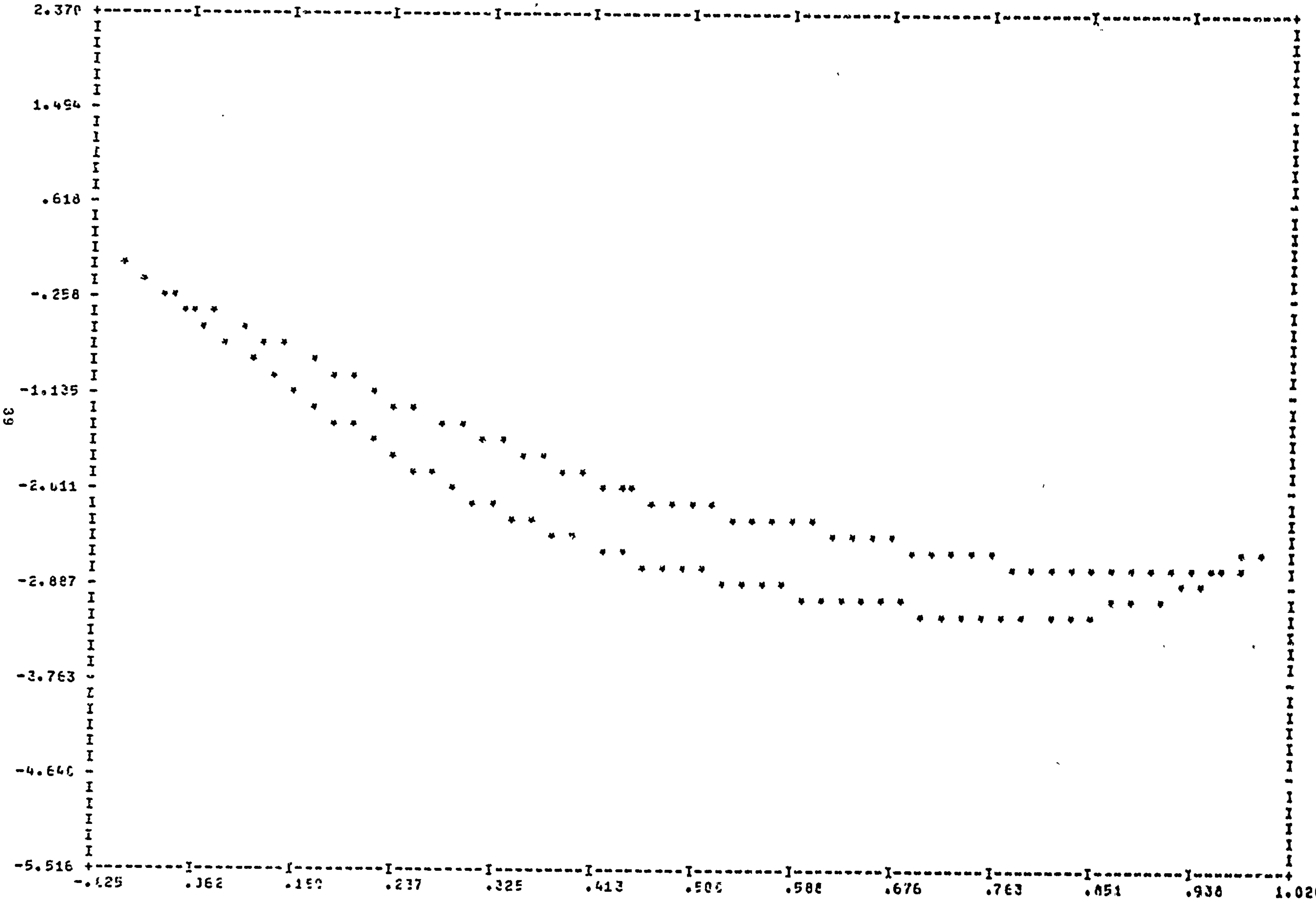
```
BLADE CHORD    = 1.0335

STAGGER ANGLE  =-14.745

CAMBER ANGLE   =-54.633

SECTION AREA   = .04394

LOCATION OF CENTROID RELATIVE TO LEADING EDGE

          XBAR =  .50573
          YBAR = -.22597

SECOND MOMENTS OF AREA ABOUT CENTROID

          IX   =  .00021
          IY   =  .00233
          IXY  = -.00063

ANGLE OF INCLINATION OF (ONE) PRINCIPAL AXIS TO 'X' AXIS =-15.355

PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID

          IPX  = .00004       (AT-15.355 WITH 'X' AXIS)
          IPY  = .00250       (AT-15.355 WITH 'Y' AXIS)
```

POINT NUMBER	MEANLINE DATA X	Y	ANGLE	THICKNESS	SURFACE COORDINATE DATA XS	YS	XP	YP
1	.00160	0.00000	-34.579	.00320	.00251	.00132	.00069	-.00132
2	.02069	-.01318	-34.089	.00665	.02276	-.01042	.01903	-.01593
3	.04018	-.02611	-33.596	.01007	.04297	-.02192	.03740	-.03030
4	.05948	-.03881	-33.101	.01345	.06315	-.03318	.05580	-.04444
5	.07877	-.05126	-32.603	.01677	.08328	-.04420	.07425	-.05833
6	.09806	-.06349	-32.103	.02004	.10330	-.05500	.09273	-.07197
7	.11735	-.07547	-31.600	.02324	.12344	-.06557	.11126	-.08537
8	.13664	-.08722	-31.095	.02637	.14345	-.07593	.12983	-.09851
9	.15593	-.09874	-30.588	.02941	.16341	-.08608	.14845	-.11140
10	.17522	-.11003	-30.079	.03236	.18333	-.09603	.16711	-.12403
11	.19451	-.12109	-29.568	.03522	.20320	-.10577	.18582	-.13640
12	.21380	-.13192	-29.055	.03796	.22302	-.11533	.20459	-.14851
13	.23150	-.14165	-28.545	.04038	.24115	-.12391	.22185	-.15938

POINT NUMBER	MEANLINE DATA X	Y	ANGLE	THICKNESS	SURFACE COORDINATE DATA XS	YS	XP	YP
14	.24919	-.15116	-27.958	.04265	.25920	-.13231	.23919	-.17001
15	.26689	-.16042	-27.291	.04489	.27718	-.14048	.25660	-.10037
16	.28459	-.16941	-26.541	.04698	.29508	-.14839	.27409	-.19043
17	.30228	-.17809	-25.706	.04695	.31290	-.15604	.29166	-.20014
18	.31998	-.18644	-24.783	.05079	.33062	-.16338	.30933	-.20950
19	.33767	-.19442	-23.768	.05250	.34825	-.17040	.32709	-.21845
20	.35537	-.20201	-22.657	.05408	.36573	-.17706	.34495	-.22697
21	.37306	-.20919	-21.448	.05553	.38321	-.18334	.36291	-.23503
22	.39076	-.21591	-20.136	.05683	.40054	-.18923	.38098	-.24258
23	.40845	-.22215	-18.718	.05799	.41776	-.19469	.39915	-.24961
24	.42596	-.22784	-17.317	.05900	.43474	-.19968	.41718	-.25600
25	.44346	-.23308	-16.031	.05986	.45173	-.20432	.43520	-.26185
26	.46097	-.23792	-14.866	.06058	.46874	-.20864	.45319	-.26719
27	.47847	-.24239	-13.826	.06116	.48578	-.21270	.47116	-.27208
28	.49598	-.24655	-12.918	.06159	.50286	-.21653	.48909	-.27656
29	.51348	-.25043	-12.144	.06187	.51999	-.22019	.50697	-.28068
30	.53098	-.25410	-11.506	.06200	.53717	-.22372	.52480	-.28447
31	.54849	-.25758	-11.008	.06198	.55441	-.22716	.54257	-.28799
32	.56599	-.26092	-10.651	.06179	.57170	-.23056	.56028	-.29128
33	.58350	-.26418	-10.435	.06145	.58906	-.23396	.57793	-.29439
34	.60100	-.26738	-10.361	.06094	.60648	-.23741	.59552	-.29736
35	.61854	-.27058	-10.294	.06028	.62392	-.24093	.61315	-.30024
36	.63608	-.27374	-10.094	.05944	.64128	-.24448	.63087	-.30300
37	.65361	-.27681	-9.763	.05845	.65857	-.24801	.64866	-.30561
38	.67115	-.27976	-9.300	.05729	.67578	-.25149	.66652	-.30803
39	.68869	-.28254	-8.703	.05596	.69292	-.25478	.68445	-.31020
40	.70622	-.28512	-7.970	.05447	.71000	-.25814	.70245	-.31209
41	.72376	-.28744	-7.102	.05282	.72703	-.26123	.72050	-.31365
42	.74130	-.28947	-6.097	.05100	.74401	-.26412	.73859	-.31483
43	.75884	-.29117	-4.953	.04901	.76095	-.26676	.75672	-.31559
44	.77637	-.29250	-3.671	.04685	.77787	-.26912	.77487	-.31588
45	.79391	-.29341	-2.249	.04453	.79478	-.27116	.79304	-.31566
46	.81260	-.29388	-.611	.04187	.81282	-.27295	.81237	-.31481
47	.83128	-.29380	1.126	.03901	.83090	-.27430	.83166	-.31330
48	.84997	-.29313	2.958	.03595	.84904	-.27518	.85089	-.31108
49	.86865	-.29185	4.881	.03268	.86726	-.27557	.87004	-.30814
50	.88734	-.28993	6.889	.02920	.88558	-.27544	.88909	-.30443
51	.90602	-.28733	8.974	.02550	.90403	-.27474	.90801	-.29992
52	.92471	-.28402	11.130	.02156	.92262	-.27344	.92679	-.29460
53	.94339	-.27997	13.347	.01738	.94138	-.27151	.94540	-.20842
54	.96208	-.27514	15.614	.01294	.96033	-.26891	.96382	-.28137
55	.98076	-.26951	17.921	.00822	.97950	-.26560	.98202	-.27342
56	.99945	-.26305	20.254	.00320	.99889	-.26154	1.00000	-.26455

NORMALISED PLOT OF SECTION NUMBER 1

SCALES - 'X' IS SHOWN TIMES 10 TO THE POWER OF -0 'Y' IS SHOWN TIMES 10 TO THE POWER OF 1



DIMENSIONAL RESULTS - ALL RESULTS REFER TO A BLADE OF SPECIFIED CHORD
****

BLADE CHORD = 3.48493E+00

L.E.RADIUS = 5.40164E-03 CENTERED AT X= -1.70986E+00 Y= 7.61934E-01

SECTION AREA = 4.99538E-01

SECOND MOMENTS OF AREA ABOUT CENTROID

IX = 2.68937E-02
IY = 3.00714E-01
IXY =-8.13213E-02

PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID

IPX = 4.56332E-03 (AT-15.355 WITH 'X' AXIS)
IPY = 3.23044E-01 (AT-15.355 WITH 'Y' AXIS)

PT NO	SUCTION------SURFACE X	Y	PRESSURE-----SURFACE X	Y	PT NO	SUCTION------SURFACE X	Y	PRESSURE-----SURFACE X	Y
1	-1.70620E+00	7.66381E-01	-1.71293E+00	7.57486E-01	2	-1.63653E+00	7.26791E-01	-1.65110E+00	7.08216E-01
3	-1.57038E+00	6.88326E-01	-1.58916E+00	6.59750E-01	4	-1.50234E+00	6.50070E-01	-1.52710E+00	6.12092E-01
5	-1.43444E+00	6.12899E-01	-1.46491E+00	5.65255E-01	6	-1.36667E+00	5.76494E-01	-1.40259E+00	5.19247E-01
7	-1.29905E+00	5.40836E-01	-1.34012E+00	4.74080E-01	8	-1.23157E+00	5.05905E-01	-1.27750E+00	4.29763E-01
9	-1.16425E+00	4.71682E-01	-1.21472E+00	3.86304E-01	10	-1.09710E+00	4.38148E-01	-1.15179E+00	3.43715E-01
11	-1.03010E+00	4.05283E-01	-1.08869E+00	3.02003E-01	12	-9.63269E-01	3.73069E-01	-1.02543E+00	2.61178E-01
13	-9.02155E-01	3.44111E-01	-9.67211E-01	2.24516E-01	14	-8.41275E-01	3.15814E-01	-9.08758E-01	1.88670E-01
15	-7.80647E-01	2.88271E-01	-8.50053E-01	1.53745E-01	16	-7.20289E-01	2.61570E-01	-7.91079E-01	1.19843E-01
17	-6.60220E-01	2.35796E-01	-7.31814E-01	8.70756E-02	18	-6.00455E-01	2.11038E-01	-6.72246E-01	5.55459E-02
19	-5.41009E-01	1.87384E-01	-6.12360E-01	2.53600E-02	20	-4.81893E-01	1.64919E-01	-5.52143E-01	-3.37286E-03
21	-4.23122E-01	1.43722E-01	-4.91581E-01	-3.05387E-02	22	-3.64704E-01	1.23076E-01	-4.30666E-01	-5.60261E-02
23	-3.06645E-01	1.05462E-01	-3.69392E-01	-7.97227E-02	24	-2.49390E-01	8.86345E-02	-3.08603E-01	-1.01272E-01
25	-1.92104E-01	7.30086E-02	-2.47844E-01	-1.20982E-01	26	-1.34748E-01	5.84325E-02	-1.87156E-01	-1.39007E-01
27	-7.72876E-02	4.47546E-02	-1.26572E-01	-1.55496E-01	28	-1.96936E-02	3.18229E-02	-6.61219E-02	-1.70603E-01
29	3.80587E-02	1.94856E-02	-5.82985E-03	-1.84478E-01	30	9.59806E-02	7.59163E-03	5.42846E-02	-1.97274E-01
31	1.54111E-01	-4.01143E-03	1.14207E-01	-2.09142E-01	32	2.12435E-01	-1.54738E-02	1.73927E-01	-2.20236E-01
33	2.70966E-01	-2.69447E-02	2.33440E-01	-2.30709E-01	34	3.29705E-01	-3.85753E-02	2.92746E-01	-2.40714E-01
35	3.88517E-01	-5.04480E-02	3.52199E-01	-2.50416E-01	36	4.47056E-01	-6.24097E-02	4.11925E-01	-2.59744E-01
37	5.05324E-01	-7.43260E-02	4.71913E-01	-2.68554E-01	38	5.63365E-01	-8.60644E-02	5.32140E-01	-2.76697E-01
39	6.21165E-01	-9.74940E-02	5.92613E-01	-2.84025E-01	40	6.78757E-01	-1.08485E-01	6.53287E-01	-2.90386E-01
41	7.36165E-01	-1.16908E-01	7.14145E-01	-2.95636E-01	42	7.93419E-01	-1.28636E-01	7.75156E-01	-2.99615E-01
43	8.50555E-01	-1.37543E-01	8.36286E-01	-3.02173E-01	44	9.07610E-01	-1.45500E-01	8.97496E-01	-3.03157E-01
45	9.64632E-01	-1.52383E-01	9.58740E-01	-3.02414E-01	46	1.02544E+00	-1.58400E-01	1.02394E+00	-2.99561E-01
47	1.08640E+00	-1.62955E-01	1.08899E+00	-2.94457E-01	48	1.14757E+00	-1.65943E-01	1.15362E+00	-2.86991E-01
49	1.20901E+00	-1.67259E-01	1.21639E+00	-2.77057E-01	50	1.27080E+00	-1.66796E-01	1.20261E+00	-2.64547E-01
51	1.33300E+00	-1.64439E-01	1.34641E+00	-2.49360E-01	52	1.39569E+00	-1.60070E-01	1.40973E+00	-2.31401E-01
53	1.45895E+00	-1.53566E-01	1.47248E+00	-2.10580E-01	54	1.52284E+00	-1.44799E-01	1.53459E+00	-1.86809E-01
55	1.58745E+00	-1.23639E-01	1.59598E+00	-1.60004E-01	56	1.65285E+00	-1.19951E-01	1.65659E+00	-1.30086E-01

POINTS DESCRIBING LEADING EDGE RADIUS

POINT NO.	X	Y
1	-1.71293E+00	7.57486E-01
2	-1.71336E+00	7.57831E-01
3	-1.71378E+00	7.58221E-01
4	-1.71415E+00	7.58651E-01
5	-1.71447E+00	7.59110E-01
6	-1.71474E+00	7.59615E-01
7	-1.71496E+00	7.60138E-01
8	-1.71512E+00	7.60660E-01
9	-1.71522E+00	7.61236E-01
10	-1.71526E+00	7.61800E-01
11	-1.71525E+00	7.62365E-01
12	-1.71517E+00	7.62926E-01
13	-1.71504E+00	7.63475E-01
14	-1.71485E+00	7.64008E-01
15	-1.71461E+00	7.64518E-01
16	-1.71431E+00	7.64999E-01
17	-1.71396E+00	7.65448E-01
18	-1.71357E+00	7.65857E-01
19	-1.71314E+00	7.66224E-01
20	-1.71268E+00	7.66543E-01
21	-1.71218E+00	7.66812E-01
22	-1.71166E+00	7.67028E-01
23	-1.71112E+00	7.67188E-01
24	-1.71056E+00	7.67290E-01
25	-1.71000E+00	7.67334E-01
26	-1.70943E+00	7.67318E-01
27	-1.70887E+00	7.67244E-01
28	-1.70832E+00	7.67111E-01
29	-1.70779E+00	7.66921E-01
30	-1.70728E+00	7.66677E-01
31	-1.70680E+00	7.66381E-01

CARTESIAN COORDINATES ON STREAMSURFACE 1

POINT NO	ZS	XS	YS	ZP	XP	YP
1	2.57578E+00	-1.44008E+00	6.79391E-01	2.57488E+00	-1.44527E+00	6.69983E-01
2	2.62081E+00	-1.38231E+00	6.49769E-01	2.61872E+00	-1.39294E+00	6.30152E-01
3	2.66530E+00	-1.32471E+00	6.20279E-01	2.66178E+00	-1.34058E+00	5.90498E-01
4	2.70925E+00	-1.26726E+00	5.90880E-01	2.70411E+00	-1.28816E+00	5.51002E-01
5	2.75268E+00	-1.20996E+00	5.61579E-01	2.74574E+00	-1.23567E+00	5.11703E-01
6	2.79558E+00	-1.15281E+00	5.32384E-01	2.78670E+00	-1.18309E+00	4.72643E-01
7	2.83795E+00	-1.09581E+00	5.03302E-01	2.82702E+00	-1.13042E+00	4.33856E-01
8	2.87980E+00	-1.03895E+00	4.74340E-01	2.86671E+00	-1.07765E+00	3.95394E-01
9	2.92113E+00	-9.82233E-01	4.45503E-01	2.90581E+00	-1.02475E+00	3.57260E-01
10	2.96194E+00	-9.25647E-01	4.16797E-01	2.94435E+00	-9.71731E-01	3.19507E-01
11	3.00224E+00	-8.69188E-01	3.88229E-01	2.98234E+00	-9.18567E-01	2.82142E-01
12	3.04201E+00	-8.12852E-01	3.59810E-01	3.01981E+00	-8.65253E-01	2.45204E-01
13	3.07802E+00	-7.61318E-01	3.33904E-01	3.05376E+00	-8.16176E-01	2.11720E-01
14	3.11357E+00	-7.09968E-01	3.08275E-01	3.08736E+00	-7.66887E-01	1.78735E-01
15	3.14865E+00	-6.58818E-01	2.83013E-01	3.12065E+00	-7.17373E-01	1.46309E-01
16	3.18328E+00	-6.07888E-01	2.58203E-01	3.15367E+00	-6.67620E-01	1.14560E-01
17	3.21746E+00	-5.57193E-01	2.34006E-01	3.18646E+00	-6.17614E-01	8.36502E-02

POINT NO	ZS	XS	YS	ZP	XP	YP
18	3.25119E+00	-5.06751E-01	2.10564E-01	3.21906E+00	-5.67343E-01	5.37112E-02
19	3.28450E+00	-4.56573E-01	1.87920E-01	3.25152E+00	-5.16799E-01	2.48061E-02
20	3.31739E+00	-4.06673E-01	1.66147E-01	3.28390E+00	-4.65971E-01	-2.93534E-03
21	3.34990E+00	-3.57064E-01	1.45434E-01	3.31623E+00	-4.14851E-01	-2.93572E-02
22	3.38203E+00	-3.07756E-01	1.25900E-01	3.34857E+00	-3.63432E-01	-5.42882E-02
23	3.41381E+00	-2.58754E-01	1.07566E-01	3.38097E+00	-3.11713E-01	-7.76772E-02
24	3.44503E+00	-2.10439E-01	9.05985E-02	3.41302E+00	-2.60406E-01	-9.91429E-02
25	3.47615E+00	-1.62093E-01	7.47768E-02	3.44499E+00	-2.09131E-01	-1.18983E-01
26	3.50722E+00	-1.13695E-01	5.98300E-02	3.47690E+00	-1.57917E-01	-1.37239E-01
27	3.53827E+00	-6.52108E-02	4.56249E-02	3.50873E+00	-1.06796E-01	-1.54107E-01
28	3.56934E+00	-1.66159E-02	3.20936E-02	3.54049E+00	-5.57894E-02	-1.69744E-01
29	3.60043E+00	3.21106E-02	1.90469E-02	3.57217E+00	-4.91876E-03	-1.84299E-01
30	3.63158E+00	8.09859E-02	6.31238E-03	3.60377E+00	4.58005E-02	-1.97856E-01
31	3.66278E+00	1.30023E-01	-6.22534E-03	3.63527E+00	9.63565E-02	-2.10575E-01
32	3.69405E+00	1.79230E-01	-1.86887E-02	3.66667E+00	1.46741E-01	-2.22632E-01
33	3.72539E+00	2.28612E-01	-3.12768E-02	3.69797E+00	1.96951E-01	-2.34168E-01
34	3.75660E+00	2.78169E-01	-4.41188E-02	3.72916E+00	2.46987E-01	-2.45314E-01
35	3.78820E+00	3.27789E-01	-5.72821E-02	3.76042E+00	2.97148E-01	-2.56238E-01
36	3.81940E+00	3.77180E-01	-7.06083E-02	3.79182E+00	3.47540E-01	-2.66890E-01
37	3.85042E+00	4.26351E-01	-8.39795E-02	3.82337E+00	3.98153E-01	-2.77138E-01
38	3.88127E+00	4.75313E-01	-9.72590E-02	3.85508E+00	4.48975E-01	-2.86795E-01
39	3.91196E+00	5.24082E-01	-1.10269E-01	3.88695E+00	4.99992E-01	-2.95709E-01
40	3.94251E+00	5.72679E-01	-1.22881E-01	3.91900E+00	5.51185E-01	-3.03773E-01
41	3.97294E+00	6.21112E-01	-1.35037E-01	3.95121E+00	6.02533E-01	-3.10827E-01
42	4.00328E+00	6.69420E-01	-1.46540E-01	3.98360E+00	6.54011E-01	-3.16636E-01
43	4.03357E+00	7.17627E-01	-1.57192E-01	4.01616E+00	7.05589E-01	-3.21038E-01
44	4.06383E+00	7.65767E-01	-1.66934E-01	4.04889E+00	7.57233E-01	-3.23994E-01
45	4.09409E+00	8.13878E-01	-1.75753E-01	4.08176E+00	8.08906E-01	-3.25300E-01
46	4.12642E+00	8.65183E-01	-1.83771E-01	4.11692E+00	8.62914E-01	-3.24608E-01
47	4.15888E+00	9.16614E-01	-1.90288E-01	4.15218E+00	9.18796E-01	-3.21628E-01
48	4.19152E+00	9.60222E-01	-1.95189E-01	4.18750E+00	9.73500E-01	-3.16241E-01
49	4.22439E+00	1.02006E+00	-1.98421E-01	4.22284E+00	1.02797E+00	-3.08315E-01
50	4.25752E+00	1.07219E+00	-1.99973E-01	4.25815E+00	1.08216E+00	-2.97855E-01
51	4.29097E+00	1.12467E+00	-1.99567E-01	4.29338E+00	1.13599E+00	-2.84696E-01
52	4.32477E+00	1.17757E+00	-1.97042E-01	4.32846E+00	1.18941E+00	-2.68643E-01
53	4.35897E+00	1.23094E+00	-1.92257E-01	4.36334E+00	1.24235E+00	-2.49569E-01
54	4.39361E+00	1.28485E+00	-1.85063E-01	4.39793E+00	1.29476E+00	-2.27356E-01
55	4.42871E+00	1.33937E+00	-1.75321E-01	4.43216E+00	1.34656E+00	-2.01093E-01
56	4.46431E+00	1.39455E+00	-1.62832E-01	4.46593E+00	1.39771E+00	-1.72984E-01

POINT NO	ZSEMI	XSEMI	YSEMI
1	2.57488E+00	-1.44527E+00	6.69983E-01
2	2.57456E+00	-1.44569E+00	6.70258E-01
3	2.57425E+00	-1.44600E+00	6.70581E-01
4	2.57396E+00	-1.44631E+00	6.70949E-01
5	2.57368E+00	-1.44658E+00	6.71358E-01
6	2.57341E+00	-1.44681E+00	6.71804E-01
7	2.57317E+00	-1.44699E+00	6.72281E-01
8	2.57295E+00	-1.44712E+00	6.72784E-01
9	2.57276E+00	-1.44721E+00	6.73309E-01
10	2.57259E+00	-1.44725E+00	6.73848E-01
11	2.57246E+00	-1.44723E+00	6.74397E-01
12	2.57235E+00	-1.44717E+00	6.74949E-01
13	2.57228E+00	-1.44706E+00	6.75498E-01
14	2.57224E+00	-1.44690E+00	6.76039E-01
15	2.57224E+00	-1.44669E+00	6.76564E-01
16	2.57227E+00	-1.44644E+00	6.77069E-01

POINT NO	ZSEMI	XSEMI	YSEMI
17	2.57233E+00	-1.44615E+00	6.77548E-01
18	2.57243E+00	-1.44582E+00	6.77996E-01
19	2.57255E+00	-1.44545E+00	6.78407E-01
20	2.57271E+00	-1.44506E+00	6.78777E-01
21	2.57290E+00	-1.44464E+00	6.79103E-01
22	2.57311E+00	-1.44420E+00	6.79380E-01
23	2.57335E+00	-1.44374E+00	6.79606E-01
24	2.57361E+00	-1.44327E+00	6.79778E-01
25	2.57389E+00	-1.44279E+00	6.79894E-01
26	2.57418E+00	-1.44231E+00	6.79953E-01
27	2.57449E+00	-1.44184E+00	6.79954E-01
28	2.57481E+00	-1.44137E+00	6.79898E-01
29	2.57513E+00	-1.44092E+00	6.79784E-01
30	2.57545E+00	-1.44049E+00	6.79615E-01
31	2.57578E+00	-1.44008E+00	6.79391E-01

BLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS
****

STATION 3 NUMBER OF RADII= 6

RADIUS	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
3.0363	-34.5568	-5.7373	.1506	.1030
4.0696	-39.5746	-2.4342	.1002	.1238
5.2456	-45.2380	-2.5753	.0763	.1326
6.4975	-51.2117	-1.0540	.0541	.1424
7.8091	-57.5491	2.4170	.0419	.1388
8.5000	-60.9948	2.7736	.0373	.1350

STATION 4 NUMBER OF RADII= 6

RADIUS	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
3.3893	-25.0291	-5.4105	.1931	.0062
4.3344	-31.0059	-2.1189	.1407	.0223
5.4154	-38.8179	-3.6777	.1073	.0305
6.5824	-47.5182	-3.3044	.0795	.0462
7.8307	-55.7777	.4414	.0341	.0490
8.5000	-59.8318	.6624	.0595	.0482

STATION 5 NUMBER OF RADII= 6

RADIUS	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
3.7385	-12.8974	-.4802	.1783	-.0379
4.5798	-20.6393	1.8574	.1366	.0403
5.5662	-32.2241	-.5642	.1076	-.0453
6.6591	-43.3122	-3.2075	.0847	-.0369
7.8499	-53.2632	-3.0393	.0707	-.0290
8.5000	-58.3035	-4.1039	.0674	-.0240

STATION 6 NUMBER OF RADII= 6

RADIUS	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
4.0884	-.6510	3.8433	.1186	-.0610
4.8259	-8.6767	9.3017	.0958	-.0832
5.7147	-23.7341	6.1020	.0751	-.1076
6.7242	-38.5832	-1.5136	.0668	-.1115
7.8575	-50.1964	-4.9335	.0608	-.1033
8.5000	-56.4561	-7.4341	.0613	-.0948

STATION 7 NUMBER OF RADII= 6

RADIUS	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
4.4612	38.0404	21.8805	.0108	-.0386
5.0795	11.3631	23.1255	.0143	-.0924
5.8623	-14.4548	17.0305	.0034	-.1486
6.7858	-33.9363	5.1628	.0059	-.1758
7.8716	-47.4131	-5.0787	.0046	-.1770
8.5000	-53.4651	-11.9278	.0076	-.1656

BLADE SURFACE GEOMETRY IN CARTESIAN COORDINATES AT SPECIFIED VALUES OF 'Z'

SECTION NUMBER 1 'Z' = 2.5000

SECTION PROPERTIES

SECTION AREA		=	4.3539E-01
LOCATION OF CENTROID RELATIVE TO STACK AXIS	XBAR	=	-8.1846E-02
	YBAR	=	8.9764E-02
SECOND MOMENTS OF AREA ABOUT CENTROID	IX	=	1.3782E-02
	IY	=	1.5176E-01
	IXY	=	-6.9456E-03
PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID	IPX	=	1.3204E-02 (AT -3.69 DEGREES TO 'X' AXIS)
	IPY	=	1.5234E-01 (AT -3.69 DEGREES TO 'Y' AXIS)
TORSIONAL CONSTANT		=	5.2483E-03

SECTION COORDINATES

POINT NO	XS	YS	XP	YP
1	-1.44001E+00	6.62066E-01	-1.44511E+00	6.52778E-01
2	-1.38221E+00	6.23323E-01	-1.39263E+00	6.03771E-01
3	-1.32456E+00	5.85687E-01	-1.34005E+00	5.55753E-01
4	-1.26704E+00	5.49081E-01	-1.28734E+00	5.08661E-01
5	-1.20964E+00	5.13470E-01	-1.23447E+00	4.62494E-01
6	-1.15234E+00	4.78814E-01	-1.18142E+00	4.17246E-01
7	-1.09513E+00	4.45071E-01	-1.12818E+00	3.72926E-01
8	-1.03801E+00	4.12206E-01	-1.07475E+00	3.29548E-01
9	-9.80971E-01	3.80153E-01	-1.02110E+00	2.87040E-01
10	-9.24008E-01	3.48853E-01	-9.67243E-01	2.45386E-01
11	-8.67123E-01	3.18240E-01	-9.13172E-01	2.04565E-01
12	-8.10307E-01	2.88257E-01	-8.58896E-01	1.64563E-01
13	-7.61139E-01	2.63141E-01	-8.11443E-01	1.30679E-01
14	-7.12531E-01	2.38813E-01	-7.64062E-01	9.76913E-02
15	-6.64526E-01	2.15356E-01	-7.16732E-01	6.56798E-02
16	-6.17158E-01	1.92875E-01	-6.69433E-01	3.47820E-02
17	-5.70473E-01	1.71620E-01	-6.22150E-01	5.21168E-03
18	-5.24507E-01	1.51854E-01	-5.74863E-01	-2.28647E-02
19	-4.79303E-01	1.33574E-01	-5.27566E-01	-4.94102E-02
20	-4.34902E-01	1.16868E-01	-4.80238E-01	-7.41219E-02
21	-3.91358E-01	1.02111E-01	-4.32870E-01	-9.67267E-02
22	-3.48707E-01	8.96025E-02	-3.85448E-01	-1.16884E-01
23	-3.06999E-01	7.94374E-02	-3.37976E-01	-1.34486E-01
24	-2.64881E-01	7.09582E-02	-2.89695E-01	-1.49950E-01
25	-2.23028E-01	6.47642E-02	-2.41839E-01	-1.62525E-01
26	-1.81382E-01	6.04421E-02	-1.94489E-01	-1.72093E-01
27	-1.39893E-01	5.78008E-02	-1.47741E-01	-1.79023E-01
28	-9.85226E-02	5.69800E-02	-1.01673E-01	-1.83634E-01
29	-5.72268E-02	5.72920E-02	-5.63686E-02	-1.86170E-01
30	-1.59913E-02	5.85703E-02	-1.18989E-02	-1.86619E-01
31	2.52156E-02	6.06622E-02	3.16699E-02	-1.85335E-01
32	6.64090E-02	6.32903E-02	7.42715E-02	-1.82722E-01
33	1.07567E-01	6.59070E-02	1.15659E-01	-1.79194E-01
34	1.48727E-01	6.83091E-02	1.56375E-01	-1.74940E-01

POINT NO	XS	YS	XP	YP
35	1.87827E-01	7.07226E-02	1.94538E-01	-1.69955E-01
36	2.25936E-01	7.29277E-02	2.32328E-01	-1.64692E-01
37	2.63043E-01	7.50131E-02	2.69747E-01	-1.58903E-01
38	2.99151E-01	7.73488E-02	3.06779E-01	-1.52265E-01
39	3.34271E-01	8.03610E-02	3.43413E-01	-1.44451E-01
40	3.68422E-01	8.43596E-02	3.79642E-01	-1.35235E-01
41	4.01630E-01	8.92567E-02	4.15442E-01	-1.24240E-01
42	4.33945E-01	9.57912E-02	4.50806E-01	-1.10735E-01
43	4.65402E-01	1.04638E-01	4.85701E-01	-9.43730E-02
44	4.96101E-01	1.15936E-01	5.20122E-01	-7.52074E-02
45	5.26081E-01	1.29543E-01	5.54018E-01	-5.25993E-02
46	5.65661E-01	1.47128E-01	5.98442E-01	-2.30496E-02
47	6.05137E-01	1.69887E-01	6.42467E-01	1.30288E-02
48	6.44567E-01	1.98633E-01	6.85914E-01	5.62132E-02
49	6.84044E-01	2.33723E-01	7.28558E-01	1.07248E-01
50	7.23652E-01	2.75563E-01	7.70158E-01	1.66419E-01
51	7.63492E-01	3.25882E-01	8.10429E-01	2.34813E-01
52	8.03664E-01	3.86627E-01	8.49057E-01	3.14310E-01
53	8.44294E-01	4.58989E-01	8.85717E-01	4.05505E-01
54	8.85492E-01	5.44508E-01	9.20050E-01	5.09385E-01
55	9.27413E-01	6.45143E-01	9.51715E-01	6.27039E-01
56	9.70161E-01	7.63431E-01	9.80319E-01	7.59971E-01

POINT NO	XSEMI	YSEMI
1	-1.44511E+00	6.52778E-01
2	-1.44549E+00	6.53122E-01
3	-1.44584E+00	6.53514E-01
4	-1.44616E+00	6.53948E-01
5	-1.44643E+00	6.54420E-01
6	-1.44666E+00	6.54925E-01
7	-1.44685E+00	6.55458E-01
8	-1.44699E+00	6.56012E-01
9	-1.44708E+00	6.56581E-01
10	-1.44712E+00	6.57160E-01
11	-1.44711E+00	6.57742E-01
12	-1.44705E+00	6.58320E-01
13	-1.44695E+00	6.58888E-01
14	-1.44679E+00	6.59440E-01
15	-1.44659E+00	6.59971E-01
16	-1.44634E+00	6.60473E-01
17	-1.44606E+00	6.60942E-01
18	-1.44573E+00	6.61372E-01
19	-1.44537E+00	6.61759E-01
20	-1.44498E+00	6.62099E-01
21	-1.44456E+00	6.62387E-01
22	-1.44412E+00	6.62621E-01
23	-1.44366E+00	6.62798E-01
24	-1.44319E+00	6.62916E-01
25	-1.44272E+00	6.62973E-01
26	-1.44224E+00	6.62970E-01
27	-1.44177E+00	6.62906E-01
28	-1.44130E+00	6.62782E-01
29	-1.44085E+00	6.62599E-01
30	-1.44042E+00	6.62360E-01
31	-1.44031E+00	6.62066E-01

SECTION VII

COMPUTER PROGRAM DETAILS

1. IMPLEMENTATION OF THE COMPUTER PROGRAM

The program is written in FORTRAN IV and was developed on a CDC 6000 Series System, incorporating the version 3.3 SCOPE Operating System. When loaded into core, the program (and resident system) occupies about 32K of storage, so that the program will probably not be usable without modification on a relatively small computer. Apart from this limitation, the program should be compatible with the majority of modern computing systems. The program consists of a main program, and Subroutines BQ, CQ, D1, EQ, and FQ. The six decks have been given the identifiers A, B, C, D, E, and F, respectively. Listings of the decks are shown below, and the deck set-up required for the CDC 6000 Series System is also presented.

The program uses three numerical system units for its input and output routines. Input is drawn from the card unit via READ statements referring to Unit LOG 1; output is sent to the line printer by WRITE statements referring to Unit LOG 2; and punched output is produced via WRITE statements referenced to Unit LOG 3. Units LOG 1, LOG 2, and LOG 3 are set equal to 5, 6, and 7, respectively, on cards A130-140 in the FORTRAN programming. On the CDC 6000 Series System, the "PROGRAM" card must also establish the input and output linkages. On other computing systems, the "PROGRAM" card may not be required, and the input-output files may be established via control cards.

The program as presented herein utilizes an on-line precision plotting capability available at the program development site. Calls to four subroutines not included in the deck are included in the program. These calls are executed only if precision plots are specified in the input data, and the entry points expressed are part of standard CALCOMP software normally supplied to users of CALCOMP precision plotting equipment. The various call statements used in the program are explained below, to facilitate modification should the need arise.

CALL PLOT (XPLOT, YPLOT, N)

The majority of plotting is done using this form of call. The parameters XPLOT and YPLOT are the "x" and "y" coordinates (in inches) on the paper to which the pen is being directed. The parameter N indicates pen up or down, $|N| = 3$ or $|N| = 2$, respectively, and will cause XPLOT or YPLOT to be assigned as the origin for further coordinates if N is negative.

CALL SYMBOL (X, Y, H, TEXT, THETA, N)

This call is used to title the plots. The parameters X and Y are the coordinates (in inches) of the lower left hand corner of the first character, H is the character height (in inches), TEXT is the character to be printed, THETA is the angle of the lettering with respect to the "x" axis and N is the total number of characters to be printed.

CALL NUMBER (X, Y, H, F, THETA, N)

This call causes the printing of the number F. The parameters X, Y, H, and THETA are used as for CALL SYMBOL. The parameter N indicates the number of digits following the decimal point if positive, or truncation to an integer if equal to -1.

CALL PLOTE

This call terminates the tape.

In the event the program is used on a computing system which does not include CALCOMP software, and the operating system will not execute a program with unsatisfied external references, dummy entry points may be supplied by adding to the deck a subroutine such as the following:

```
SUBROUTINE PLOT

A = A

ENTRY SYMBOL

ENTRY NUMBER

ENTRY PLOTE

RETURN

END
```

2. DECK SETUP FOR CDC 6000 SERIES SYSTEM

The deck setup required to run the program on a CDC 6000 Series System incorporating the SCOPE 3.3 Operating System is shown below. Production runs of the program would usually employ relocatable binary forms of the routines produced from the source decks to avoid having to compile the FORTRAN for each run and the waste of associated computer resources.

```
JOB                         Identification, etc.
FTN.
LGO.
7/8/9  End of Record
  SOURCE DECK A
  SOURCE DECK B
  SOURCE DECK C
  SOURCE DECK D
  SOURCE DECK E
  SOURCE DECK F
7/8/9  End of Record
  DATA DECK
6/7/8/9  End of Job
```

3. FORTRAN PROGRAM LISTING

A listing of the FORTRAN program appears on the following pages with each subroutine started on a new page.

```
      PROGRAM ARBITR(INPUT,OUTPUT,PUNCH,PLOT,TAPE5=INPUT,TAPE6=OUTPUT,
     1TAPE7=PUNCH)
      DIMENSION AIRANG(10,15), YPRME(81), SU(82), YU(81), BETMET(10), SM
     1(10,5), DEVCRV(10,5), RADEV(5), RINC(15), XINC(15), EXB(15), S1(10
     2), DEVRAD(10), LL(10), CELDEV(15), F137B(8), F137S(5), F161D(8,5),
     3 F195M(8,2), F164XB(8), F172K(7), F142TC(7), NPTS(15), YMPRME(81),
     4 YA(15), YB(15), YC(15), YE(15), NOINF(51), SQRARR(51), ROMIN(51)
      COMMON EPZ(100,3),R(10,15),ZOUT(15),SS(100),X(100),YPRIME(100),YS(
     115,81),YP(15,81),XP(15,81),XS(15,81),YSEMI(15,31),XSEMI(15,31),ZS(
     215,81),ZP(15,81),ZSEMI(15,31),TITLE(8),XHERE(10),XTEMP(100),RAD(10
     30),TEMP1(15),TEMP2(15),TEMP3(15),TEMP4(15),ZR(15),ZZ(15),RLE(15),T
     4C(15),TE(15),SDIVR(15),DELX(15),DELY(15),XSTA(15,10),RSTA(15,10),K
     5PTS(15),SIGMA(100),TANPHI(10,15),ZCAMB(15,10),YCAMB(15,10),IFANGS(
     610),THETA(15,10),ALPHA(15,10)
      REAL IX,IY,IXY,IPX,IPY,IXN,IYN,IXYN,IXO,IYO
      DATA F137B/0.0,10.0,20.0,30.0,40.0,50.0,60.0,70.0/
      DATA F137S/0.4,0.8,1.2,1.6,2.0/
      DATA F142TC/0.0,0.02,0.04,0.06,0.08,0.10,0.12/
      DATA F161D/0.0,0.009,0.17,0.29,0.42,0.59,0.79,1.05,0.0,0.12,0.30,0
     1.51,0.75,1.05,1.47,2.07,0.0,0.16,0.33,0.61,0.95,1.42,2.12,3.07,0.0
     2,0.17,0.40,0.72,1.11,1.71,2.62,3.95,0.0,0.2,0.44,0.78,1.21,1.90,3.
     301,4.75/
      DATA F195M/0.17,0.173,0.179,0.189,0.206,0.232,0.269,0.310,0.25,0.2
     155,0.261,0.268,0.278,0.292,0.312,0.342/
      DATA F164XB/0.965,0.945,0.921,0.890,0.850,0.782,0.679,0.550/
      DATA F172K/0.0,0.160,0.331,0.521,0.74,1.0,1.300/
      LOG1=5
      LOG2=6
      LOG3=7
      PI=3.1415926536
      C1=180.0/PI
      READ (LOG1,5) TITLE
    5 FORMAT (7A10,A2)
      WRITE (LOG2,10) TITLE
   10 FORMAT (1H1,38X,44HUSAF - ARL(LF) ARBITRARY CAMBER LINE PROGRAM,/,
     139X,44(1H*),//,10X,5HTITLE,25X,1H=,7A10,A2)
      READ (LOG1,15) NLINES,NSTNS,NZ,NSPEC,ISEGPT,NBLADE,ISTAK,IPUNCH,IF
     1PLOT,IPRINT
   15 FORMAT (12I3)
      WRITE (LOG2,20) NLINES,NSTNS,NZ,NSPEC,ISEGPT,NBLADE,ISTAK,IPUNCH,I
     1FPLOT,IPRINT
```

```
   20 FORMAT (10X,24HNUMBER OF STREAMSURFACES,6X,1H=,I3,/,10X,18HNUMBER
     1OF STATIONS,12X,1H=,I3,/,10X,27HNUMBER OF CONSTANT-Z PLANES,3X,1H=
     2,I3,/,10X,27HNUMBER OF BLADE DATA POINTS,3X,1H=,I3,/,10X,31HNUMBER
     3 OF POINTS PER SEGMENT  =,I3,/,10X,29HNUMBER OF BLADES IN BLADE RO
     4W,1X,1H=,I3,/,10X,5HISTAK,25X,1H=,I3,/,10X,6HIPUNCH,24X,1H=,I3,/,1
     50X,6HIFPLOT,24X,1H=,I3,/,10X,6HIPRINT,24X,1H=,I3)
      READ (LOG1,25) ZINNER,ZOUTER,SCALE,STACKX,PLTSZE
      WRITE (LOG2,30) ZINNER,ZOUTER,SCALE,STACKX,PLTSZE
   25 FORMAT (5F12.0)
   30 FORMAT (/,10X,6HZINNER,24X,1H=,F8.4,/,10X,6HZOUTER,24X,1H=,F8.4,/,
     110X,5HSCALE,25X,1H=,F8.4,/,10X,6HSTACKX,24X,1H=,F8.4,/,10X,6HPLTSZ
     2E,24X,1H=,F8.4,//,20X)
      READ (LOG1,15) IRLE,IRTE,NRADEV,NINC,NSIGN,IFCA,IPASS
      WRITE (LOG2,35) IRLE,IRTE,NRADEV,NINC,NSIGN,IFCA,IPASS
   35 FORMAT (10X,27HLEADING EDGE STATION NUMBER,3X,1H=,I3,/,10X,28HTRAI
     1LING EDGE STATION NUMBER,2X,1H=,I3,/,10X,26HRADII SPECIFYING DEVIA
     2TION,4X,1H=,I3,/,10X,26HRADII SPECIFYING INCIDENCE,4X,1H=,I3/10X,2
     37HSENSE OF ROTATION INDICATOR,3X,1H=,I3,/,10X,27HDEVIATION CALCULA
     4TION INDEX,3X,1H=,I3,/,10X,28HNUMBER OF INITIAL S/R TRIALS,2X,1H=,
     5I3,/,2X)
      READ (LOG1,25) XKSHPE,SOLTOL
      WRITE (LOG2,40) XKSHPE,SOLTOL
   40 FORMAT (10X,12HSHAPE FACTOR,18X,1H=,F8.4,/,10X,18HSOLIDITY TOLERAN
     1CE,12X,1H=,F8.4,//,2X)
      DO 55 K=1,NRADEV
      READ (LOG1,15) NPTS(K)
      READ (LOG1,25) RADEV(K)
      WRITE (LOG2,45) K,NPTS(K),RADEV(K)
   45 FORMAT (5X,16HDEVIATION CURVE ,I2,5X,18HNUMBER OF POINTS =,I2,5X,8
     1HRADIUS =,F8.4,/,2X)
      NPT=NPTS(K)
      READ (LOG1,50) (SM(J,K),DEVCRV(J,K),J=1,NPT)
   50 FORMAT (2F12.0)
   55 WRITE (LOG2,60) (J,SM(J,K),DEVCRV(J,K),J=1,NPT)
   60 FORMAT (10X,5HPOINT,5X,22HNORMALIZED MERIDIONAL,5X,20HNORMALIZED
     1DEVIATION,/,28X,5HCHORD,18X,12HDISTRIBUTION,//(11X,I2,14X,F6.4,20X
     2,F6.4))
      READ (LOG1,65) (RINC(J),XINC(J),DELDEV(J),J=1,NINC)
   65 FORMAT (3F12.0)
      WRITE (LOG2,70) (RINC(J),XINC(J),DELDEV(J),J=1,NINC)
```

```
70    FORMAT (2X,//,5X,42HINCIDENCE AND EXTRA DEVIATION DISTRIBUTION,//,
     110X,12HINLET RADIUS,4X,9HINCIDENCE,4X,15HEXTRA DEVIATION,//(F19.4,
     2F14.3,F15.3))
      LNCT=3
      WRITE (LOG2,75)
75    FORMAT (1H1,//,20X,36HSTREAMSURFACE GEOMETRY SPECIFICATION)
      DO 120 I=1,NSTNS
      READ (LOG1,15) KPTS(I),IFANGS(I),LOG8
      IF (LOG8.EQ.0) LOG8=5
      KPT=KPTS(I)
      READ (LOG1,50) (XSTA(K,I),RSTA(K,I),K=1,KPT)
      IF (KPTS(I).GE.2) GO TO 80
      KPTS(I)=2
      XSTA(2,I)=XSTA(1,I)
      RSTA(2,I)=RSTA(1,I)+1.0
80    READ (LOG8,50) (R(I,J),AIRANG(I,J),J=1,NLINES)
      IDUM=KPTS(I)
      IF (NLINES.GT.IDUM) IDUM=NLINES
      IF (LNCT.LE.54-NLINES) GO TO 90
      WRITE (LOG2,85)
85    FORMAT (1H1)
      LNCT=1
90    LNCT=LNCT+IDUM+6
      WRITE (LOG2,95) I,KPTS(I),I,IFANGS(I)
95    FORMAT (2X,/,10X,17HCOMPUTING STATION,I3,5X,28HNUMBER OF DESCRIBIN
     1G POINTS=,I3,6X,7HIFANGS(,I2,2H)=,I3,//6X,11HDESCRIPTION,9X,10HSTR
     2EAMLINE,5X,5HRADII,11X,9HAIR ANGLE,/,6X,1HX,9X,1HR,11X,6HNUMBER,//
     3,2X)
      DO 100 K=1,IDUM
      IF (K.LE.KPTS(I).AND.K.LE.NLINES) WRITE (LOG2,105) XSTA(K,I),RSTA(
     1K,I),K,R(I,K),AIRANG(I,K)
      IF (K.LE.KPTS(I).AND.K.GT.NLINES) WRITE (LOG2,110) XSTA(K,I),RSTA(
     1K,I)
      IF (K.GT.KPTS(I).AND.K.LE.NLINES) WRITE (LOG2,115) K,R(I,K),AIRANG
     1(I,K)
100   CONTINUE
105   FORMAT (3X,F8.4,2X,F8.4,8X,I2,9X,F8.4,9X,F8.4)
110   FORMAT (3X,F8.4,2X,F8.4)
115   FORMAT (29X,I2,9X,F8.4,9X,F8.4)
120   CONTINUE
```

```
      IF (LNCT.LE.54-NSPEC) GO TO 125
      WRITE (LOG2,85)
      LNCT=1
  125 LNCT=LNCT+NSPEC+6
      READ (LOG1,130) (ZR(J),YA(J),YB(J),YC(J),YE(J),RLE(J),TC(J),TE(J),
     1ZZ(J),SDIVR(J),DELX(J),DELY(J),J=1,NSPEC)
  130 FORMAT (6F12.0)
      WRITE (LOG2,135) (ZR(J),YA(J),YB(J),YC(J),YE(J),RLE(J),TC(J),TE(J)
     1,ZZ(J),SDIVR(J),DELX(J),DELY(J),J=1,NSPEC)
  135 FORMAT (2X,/,20X,30HSECTION GEOMETRY SPECIFICATION,//,10X,10HSTREA
     1MLINE,2X,5HSLD  ,5X,6HIN.DEL,4X,6HCONSID,4X,6HNO.ALD,3X,48HLE RADI
     2US MAX THICK TE THICK  POINT OF START VAL,3X,7HX STACK,3X,7HY STAC
     3K,/,11X,6HNUMBER,5X,5HCL FT,5X,5H S/R0,3X,19HLE RD CRV INFL. PTS,3
     4X,6H/CHORD,4X,6H/CHORD,3X,8H/2*CHORD,2X,18HMAX THICK  OF S/R ,4X,6
     5HOFFSET,4X,6HOFFSET,//,(10X,F7.2,3X,F8.3,F10.3,2F10.4,3F10.5,2F10.
     64,F11.6,F10.6))
      IF (IFPLOT.EQ.4) CALL PLOT (0.0,-PLTSZE,-3)
      IF (IFPLOT.EQ.0.OR.IFPLOT.EQ.4) GO TO 140
      IKDUM=0
      IF ((AIRANG(IRLE,1)-AIRANG(IRTE,1)).LT.0.) IKDUM=1
      IF (IFPLOT.EQ.1.OR.IFPLOT.EQ.3) CALL FQ (ISTAK,PLTSZE,1,TITLE,IKDU
     1M,IFPLOT)
  140 DO 465 J=1,NLINES
      DO 145 I=IRLE,IRTE
      KPT=KPTS(I)
  145 CALL D1 (RSTA(1,I),XSTA(1,I),KPT,R(I,J),XHERE(I),1,0)
      X(1)=XHERE(IRLE)
      X(100)=XHERE(IRTE)
      AX=(X(100)-X(1))/99.0
      DO 150 I=2,99
  150 X(I)=X(I-1)+AX
      ICORIT=IRTE-IRLE+1
      CALL CQ (XHERE(IRLE),R(IRLE,J),ICORIT,X,XDUM,YPRIME,100,1)
      SS(1)=0.0
      DO 155 I=2,100
  155 SS(I)=SS(I-1)+AX*SQRT(1.0+((YPRIME(I)+YPRIME(I-1))/2.0)**2)
      XJ=J
      CALL D1 (ZR,RLE,NSPEC,XJ,YZERO,1,0)
      CALL D1 (ZR,TC,NSPEC,XJ,T,1,0)
      CALL D1 (ZR,TE,NSPEC,XJ,YONE,1,0)
```

```
      CALL D1 (ZR,DELX,NSPEC,XJ,XDEL,1,0)
      CALL D1 (ZR,DELY,NSPEC,XJ,YDEL,1,0)
      CALL D1 (ZR,ZZ,NSPEC,XJ,Z,1,0)
      CALL D1 (ZR,YA,NSPEC,XJ,SSOLID,1,0)
      CALL D1 (ZR,SDIVR,NSPEC,XJ,SDR,1,0)
      CALL D1 (ZR,YB,NSPEC,XJ,DELSDR,1,0)
      CALL D1 (ZR,YC,NSPEC,XJ,RDLEMN,1,0)
      CALL D1 (ZR,YE,NSPEC,XJ,ACCIFP,1,0)
      IJ=IPASS-1
      LMN=0
      IJK=-1
      PRNT=0.
      XSIGN=NSIGN
      STAGER=(AIRANG(IRLE,J)+AIRANG(IRTE,J))/2.
      RINSCL=(R(IRLE,J)+R(IRTE,J))/2.
      SDR1=SDR
  160 CHORD=SS(100)/COS(STAGER/C1)
      IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TO 170
      IF (IJK.EQ.3) WRITE (LOG2,165) SDR
  165 FORMAT (1H1,9X,15HOPTIMAL SECTION,/,10X,15(1H*),//,10X,11HFINAL S/
     1R =,F8.4,//,10X,23HITERATIONS ON SOLIDITY )
  170 SOLID=CHORD/RINSOL/2./PI*FLOAT(NBLADE)
      CALL D1 (RINC,XINC,NINC,R(IRLE,J),TEMP2,1,0)
      CALL D1 (RINC,DELDEV,NINC,R(IRLE,J),TEMP3,1,0)
      BETMET(1)=AIRANG(IRLE,J)-XSIGN*TEMP2(1)
      BETS=AIRANG(IRLE,J)*XSIGN
      DO 175 K=1,5
  175 CALL D1 (F137B,F161C(1,K),8,BETS,EXB(K),1,0)
      CALL D1 (F137B,F195M(1,IFCA),8,BETS,XMS,1,0)
      CALL D1 (F137B,F16 NB,8,BETS,XTEMP,1,0)
      CALL D1 (ZR,TC,NSPEC,XJ,X1,1,0)
      CALL D1 (F142TC,F172K,7,X1,XKDT,1,0)
      BETS=BETMET(1)*XSIGN
      NN=0
  180 NN=NN+1
      IF (NN.GT.20) GO TO 700
      CALL C1 (F137S,EXB,5,SOLID,DO,1,1)
      XMM=XMS/SOLID**XTEMP(1)
      DEV=(DO*XKDT*XKSHPE+XMM*(BETS-XSIGN*AIRANG(IRTE,J))+TEMP3(1))*1.0/
     1(1.-XMM)
```

```
      IF (IJK.EQ.3.AND.IPRINT.NE.2) WRITE (LOG2,185) NN,DEV,SCLIC
185   FORMAT (33X,10HITERATION ,I2,3X,11HDEVIATION =,F7.3,3X,10HSOLIDITY
     1 =,F7.4)
      MN=IRTE-IRLE+1
      BETMET(MN)=AIRANG(IRTE,J)-DEV*XSIGN
      S1(1)=0.
      DO 205 I=1,NSTNS
      IF (I-IRLE) 205,205,190
190   IF (IRTE-I) 205,205,195
195   L=I-IRLE+1
      CALL C1 (X,SS,100,XHERE(I),S1(L),1,1)
      S1(L)=S1(L)/SS(100)
      DO 200 K=1,NRADEV
200   CALL D1 (SM(1,K),DEVCRV(1,K),NPTS(K),S1(L),DEVRAD(K),1,0)
      CALL D1 (RADEV,DEVRAD,NRADEV,R(IRTE,J),DEVPCT,1,0)
      BETMET(L)=AIRANG(I,J)-DEV*DEVPCT*XSIGN
205   CONTINUE
      S1(MN)=1.
      YP1=TAN(BETMET(1)/C1)
      YMPRME(1)=YP1
      YU(1)=0.
      IPOINT=1
      SU(1)=0.
      Y1=0.
      YPP1=SDR/2./PI/R(IRLE,J)*FLOAT(NBLADE)*(1.+YP1*YP1)**(1.5)
      YPPME(1)=YPP1
      IF (YPP1.NE.0.) GO TO 210
      YPRIME(1)=1000.
      GO TO 215
210   CONTINUE
      YPRIME(1)=(1.+YMPRME(1)*YMPRME(1))**(1.5)/YPPME(1)
215   CONTINUE
      S11=0.
      S12=0.
      LL(1)=0
      DO 230 K=2,MN
      YP2=TAN(BETMET(K)/C1)
      LL(K)=0
      S2=S1(K)
      S22=S2*S2
```

```
      A=(YP2-YP1-YPP1*(S2-S11))/3./(S22-S12-2.*S11*(S2-S11))
      B=(YPP1-6.*A*S11)/2.
      C=YP1-3.*A*S12-2.*B*S11
      D=Y1-A*S12*S11-B*S12-C*S11
      SDIFF=(S2-S11)/FLOAT(ISEGPT-1)
      KL=IPOINT+1
      KJ=IPOINT+ISEGPT-1
      DO 225 L=KL,KJ
      SU(L)=SU(L-1)+SDIFF
      YU(L)=D+SU(L)*(C+SU(L)*(B+A*SU(L)))
      YMPRME(L)=C+SU(L)*(B*2.+A*3.*SU(L))
      YPPME(L)=6.*A*SU(L)+2.*B
      IF (YPPME(L).EQ.0.) YPRIME(L)=1000.
      IF (YPPME(L).EQ.0.) GO TO 225
      YPRIME(L)=(1.+YMPRME(L)*YMPRME(L))**(1.5)/YPPME(L)
      SLPE=ABS(YPPME(L)-YPPME(L-1))
      IF (SLPE.GE.ABS(YPPME(L)).AND.SLPE.GE.ABS(YPPME(L-1))) GO TO 220
      GO TO 225
220   LL(K)=L
225   CONTINUE
      IPOINT=KJ
      Y1=YU(IPOINT)
      YPP1=YPPME(KJ)
      S11=S2
      S12=S22
230   YP1=YP2
      IS=0
      DO 235 K=1,MN
      IF (LL(K).NE.0) IS=IS+1
235   CONTINUE
      CHORD1=SQRT(YU(IPOINT)**2+1.)*SS(100)
      CALL D1 (SU,YU,IPOINT,SSOLID,YSOLID,1,1)
      CHORD=SQRT((SU(IPOINT)-SSOLID)**2+(YU(IPOINT)-YSOLID)**2)*SS(100)
      SOLID1=CHORD/RINSOL/2./PI*FLOAT(NBLADE)
      DIFF=SOLID-SOLID1
      IF (ABS(DIFF).LT.SOLTOL*SOLID) GO TO 240
      SOLID=SOLID1
      GO TO 180
240   IF (IJK.EQ.3.AND.IPRINT.NE.2) WRITE (LOG2,185) NN,DEV,SOLID1
      IF (IJK.EQ.3) GO TO 305
```

```
      LMN=LMN+1
      NOINF(LMN)=IS
      SDRARR(LMN)=SDR
      SDR=SDR+DELSDR
      RDMIN(LMN)=1000.
      DO 245 L=1,IPOINT
      IF (L.EQ.1.AND.ROLEMN.EQ.1.0) GO TO 245
      IF (ABS(YPRIME(L)).LT.RDMIN(LMN)) RDMIN(LMN)=ABS(YPRIME(L))
245   CONTINUE
      IF (LMN.LE.IJ.AND.IJK.LE.0) GO TO 160
      IF (LMN.GT.IJ.AND.IJK.LE.0) GO TO 250
      IF (LMN.GT.19) GO TO 250
      GO TO 160
250   IF (LMN.EQ.20.OR.LMN.EQ.IPASS) IJK=IJK+1
      IF (IJK.EQ.2.OR.IJK.EQ.3) GO TO 290
      NMNINF=20
      DO 255 LMN=1,IPASS
      IF (NOINF(LMN).LT.NMNINF) IFIRST=LMN
      IF (NOINF(LMN).LT.NMNINF) NMNINF=NOINF(LMN)
255   CONTINUE
      IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TO 275
      WRITE (LOG2,85)
      IF (FLOAT(NMNINF).GE.(ACCIFF+1.).AND.IPRINT.NE.2) WRITE (LOG2,260)
     1
260   FORMAT (74H NOTE THAT THE MINIMUM NUMBER OF INFLECTION POINTS IS G
     1REATER THAN DESIRED,/2X)
      INDEX=IJK+1
      WRITE (LOG2,265) J,INDEX,SDR1,DELSDR
265   FORMAT (5X,14HSTREAMSURFACE ,I2,/10X,10HITERATION ,I2,/,10X,12(1H*
     1),//,10X,14HINITIAL S/R = ,F8.4,10X,17HINCREMENTAL S/R =,F8.4,//,1
     25X,8HPASS NO.,5X,21HNO. OF INFLECTION PTS,5X,24HMIN. RADIUS OF CUR
     3VATURE,/,2X)
      WRITE (LOG2,270) (LMN,NOINF(LMN),RDMIN(LMN),LMN=1,IPASS)
270   FORMAT (18X,I2,18X,I2,22X,F8.3)
275   ILAST=0
      DO 280 LMN=IFIRST,IPASS
      IF (NOINF(LMN).GT.NMNINF) ILAST=LMN
      IF (NOINF(LMN).GT.NMNINF) GO TO 285
280   CONTINUE
      ILAST=IPASS
```

```
285   IF (IJK.EQ.0) IFIRST=IFIRST-1
      IF (IFIRST.EQ.0) IFIRST=1
      IF (IFIRST.EQ.IPASS) IFIRST=IJ
      IF (IJK.EQ.1.AND.NOINF(IPASS).GT.NMNINF) ILAST=ILAST-1
      IF (ILAST.EQ.IFIRST) ILAST=ILAST+1
      IF (ILAST.EQ.(IPASS+1).OR.ILAST.EQ.0) ILAST=IPASS
      IF (IJK.EQ.0) LJ=IPASS-1
      IF (IJK.EQ.1) LJ=19
      DELSDR=(SDRARR(ILAST)-SDRARR(IFIRST))/FLOAT(LJ)
      SDR=SDRARR(IFIRST)
      SDR1=SDR
      LMN=0
      GO TO 160
290   RADMX=0.
      DO 295 L=1,20
      IF (RDMIN(L).GT.RADMX.AND.NOINF(L).EQ.NMNINF) LMN=L
      IF (RDMIN(L).GT.RADMX.AND.NOINF(L).EQ.NMNINF) RADMX=RDMIN(L)
295   CONTINUE
      IF (LMN.EQ.1.AND.IPRINT.NE.2) WRITE (LOG2,300)
      IF (LMN.EQ.20.AND.IPRINT.NE.2) WRITE (LOG2,300)
300   FORMAT (//101H THE MAXIMUM VALUE OF THE MINIMUM RADIUS OF CURVATUR
     1E OCCURS AT AN END POINT OF THE PRESENT S/R RANGE)
      IF (IJK.EQ.3) SDR=SDRARR(LMN)
      IF (IJK.EQ.3) PRNT=1.
      IF (IJK.EQ.3) GO TO 160
      SDR=SDRARR(LMN)-3.0*DELSDR
      DELSDR=6.*DELSDR/20.
      LMN=0
      GO TO 160
305   IF (IPRINT.NE.0.AND.IPRINT.NE.1) GO TO 320
      WRITE (LOG2,310)
310   FORMAT (/10X,5HPOINT,5X,22HNORMALIZED MERIDIONAL,5X,10HTANGENTIAL
     1,5X,11HCAMBER LINE,7X,6HSECOND,7X,9HRADIUS OF,/,26X,10HCOORDINATE,
     211X,10HCOORDINATE,8X,5HSLOPE,8X,10HDERIVATIVE,5X,9HCURVATURE,/2X)
      IP=IPOINT
      IF (IPOINT.GE.49) IP=48
      WRITE (LOG2,315) (L,SU(L),YU(L),YNPRME(L),YPPME(L),YPRIME(L),L=1,I
     1P)
      IF (IPOINT.GE.49) WRITE (LOG2,85)
      IF (IPOINT.GE.49) WRITE (LOG2,315) (L,SU(L),YU(L),YNPRME(L),YPPME(
```

```
     1L),YPRIME(L),L=49,IPOINT)
 315  FORMAT (12X,I2,14X,F6.4,14X,F7.4,6X,F6.4,9X,F8.4,7X,F8.3)
 320  NPOINT=IPOINT
      XNORMC=CHORD1/SS(100)
      AXIALC=SS(100)
      DO 325 I=1,NSTNS
      KPT=KPTS(I)
 325  CALL D1 (RSTA(1,I),XSTA(1,I),KPT,R(I,J),XHERE(I),1,0)
      X(1)=XHERE(1)
      X(100)=XHERE(NSTNS)
      AX=(X(100)-X(1))/99.0
      DO 330 I=2,99
 330  X(I)=X(I-1)+AX
      CALL CQ (XHERE,R(1,J),NSTNS,X,XDUM,YPRIME,100,1)
      CALL CQ (XHERE,R(1,J),NSTNS,XHERE,XDUM,TANPHI(1,J),NSTNS,1)
      SS(1)=0.0
      DO 335 I=2,100
 335  SS(I)=SS(I-1)+AX*SQRT(1.0+((YPRIME(I)+YPRIME(I-1))/2.0)**2)
      CALL D1 (X,SS,100,STACKX,EX,1,1)
      CALL BQ (J,YS,YP,XS,XP,YSEMI,XSEMI,LOGZ,IPOINT,IPRINT,BETMET(1),BE
     1TMET(MN),YZERO,T,YONE,XCEL,YDEL,Z,XNORMC,LNCT,XTEMP,YPRIME,RAD,SIG
     2MA,EPZ,XHERE,X,SS,NSTNS,R,BX,SU,YU,YMPRME,AXIALC,ISTAK)
      CALL D1 (X,SS,100,STACKX,EX,1,1)
      DO 340 I=1,100
      X(I)=X(I)-STACKX
 340  SS(I)=SS(I)-BX
      DO 345 I=1,NSTNS
 345  XHERE(I)=XHERE(I)-STACKX
      IF (IFPLOT.EQ.0.OR.IFPLOT.EQ.2.OR.IFPLOT.EQ.4) GO TO 365
      XPLOT=XS(J,1)*SCALE
      YPLOT=YS(J,1)*SCALE
      CALL PLOT (XPLOT,YPLOT,3)
      DO 350 I=2,NPOINT
      XPLOT=XS(J,I)*SCALE
      YPLOT=YS(J,I)*SCALE
 350  CALL PLOT (XPLOT,YPLOT,2)
      DO 355 II=1,NPOINT
      I=NPOINT-II+1
      XPLOT=XP(J,I)*SCALE
      YPLOT=YP(J,I)*SCALE
```

```
355   CALL PLOT (XPLOT,YPLOT,2)
      DO 360 I=2,30
      XPLOT=XSEMI(J,I)*SCALE
      YPLOT=YSEMI(J,I)*SCALE
360   CALL PLOT (XPLOT,YPLOT,2)
      XPLOT=XS(J,1)*SCALE
      YPLOT=YS(J,1)*SCALE
      CALL PLOT (XPLOT,YPLOT,2)
365   IJDUM=0
      DO 370 I=1,NSTNS
      IF (IFANGS(I).EQ.1) IJDUM=1
370   CONTINUE
      IF (IJDUM.EQ.0) GO TO 380
      CALL D1 (SS,X,100,XTEMP,XTEMP,100,1)
      DO 375 I=1,NSTNS
      CALL D1 (XTEMP,SIGMA,100,XHERE(I),THETA(J,I),1,1)
      CALL D1 (XTEMP,YPRIME,100,XHERE(I),ALPHA(J,I),1,1)
      ZCAME(J,I)=R(I,J)*COS(THETA(J,I))
375   YCAME(J,I)=R(I,J)*SIN(THETA(J,I))
380   DO 385 I=1,NPOINT
385   XTEMP(I)=XS(J,I)
      CALL D1 (SS,X,100,XTEMP,XTEMP,NPOINT,1)
      CALL D1 (XHERE,R(1,J),NSTNS,XTEMP,RAD,NPOINT,0)
      K=1
      DO 390 I=1,NPOINT
      EPS=EPZ(I,K)
      ZS(J,I)=RAD(I)*COS(EPS)
      YS(J,I)=RAD(I)*SIN(EPS)
390   XS(J,I)=XTEMP(I)
      DO 395 I=1,NPOINT
395   XTEMP(I)=XP(J,I)
      CALL D1 (SS,X,100,XTEMP,XTEMP,NPOINT,1)
      CALL D1 (XHERE,R(1,J),NSTNS,XTEMP,RAD,NPOINT,0)
      K=2
      DO 400 I=1,NPOINT
      EPS=EPZ(I,K)
      ZP(J,I)=RAD(I)*COS(EPS)
      YP(J,I)=RAD(I)*SIN(EPS)
400   XP(J,I)=XTEMP(I)
      DO 405 I=1,31
```

```
  465 XTEMP(I)=XSEMI(J,I)
      CALL D1 (SS,X,100,XTEMP,XTEMP,31,1)
      CALL D1 (XHERE,R(1,J),NSTNS,XTEMP,RAD,31,0)
      K=3
      DO 410 I=1,31
      EPS=EPZ(I,K)
      ZSEMI(J,I)=RAD(I)*COS(EPS)
      YSEMI(J,I)=RAD(I)*SIN(EPS)
  410 XSEMI(J,I)=XTEMP(I)
      IF (IPRINT.EQ.2) GO TO 465
      IF (LNCT.LE.50) GO TO 415
      WRITE (LOG2,85)
      LNCT=1
  415 LNCT=LNCT+5
      WRITE (LOG2,420) J
  420 FORMAT (2X,/,10X,38HCARTESIAN COORDINATES ON STREAMSURFACE,I3,//,1
     10X,8HPOINT NO,5X,2HZS,12X,2HXS,12X,2HYS,16X,2HZP,12X,2HXP,12X,2HYP
     2,/,2X)
      I=1
  425 WRITE (LOG2,430) I,ZS(J,I),XS(J,I),YS(J,I),ZP(J,I),XP(J,I),YP(J,I)
  430 FORMAT (10X,I5,3X,1P3E14.5,4X,1P3E14.5)
      I=I+1
      LNCT=LNCT+1
      IF (I.GT.NPOINT) GO TO 440
      IF (LNCT.LE.59) GO TO 425
      WRITE (LOG2,435)
  435 FORMAT (1H1,9X,8HPOINT NO,5X,2HZS,12X,2HXS,12X,2HYS,16X,2HZP,12X,2
     1HXP,12X,2HYP,/,2X)
      LNCT=2
      GO TO 425
  440 IF (LNCT.LE.50) GO TO 445
      WRITE (LOG2,85)
      LNCT=1
  445 LNCT=LNCT+3
      WRITE (LOG2,450)
  450 FORMAT (2X,/,10X,8HPOINT NO,4X,5HZSEMI,9X,5HXSEMI,9X,5HYSEMI,/,2X)
      I=1
  455 WRITE (LOG2,460) I,ZSEMI(J,I),XSEMI(J,I),YSEMI(J,I)
  460 FORMAT (10X,I5,3X,1P3E14.5)
      I=I+1
```

```
      LNCT=LNCT+1
      IF (I.GT.31) GO TO 465
      IF (LNCT.LE.59) GO TO 455
      WRITE (LOG2,85)
      WRITE (LOG2,450)
      LNCT=4
      GO TO 455
465   CONTINUE
      IF (IPRINT.EQ.1) GO TO 530
      VOL=0.0
      DO 470 J=2,NLINES
      VOL=VOL+(((XS(J,1)-XP(J,1))**2+(YS(J,1)-YF(J,1))**2)+((XS(J-1,1)-X
     1P(J-1,1))**2+(YS(J-1,1)-YF(J-1,1))**2))*(ZS(J,1)+ZP(J,1)-ZS(J-1,1)
     2-ZP(J-1,1))*PI/32.0
      DO 470 I=2,NPOINT
470   VOL=VOL+((SQRT((XS(J,I)-XF(J,I))**2+(YS(J,I)-YF(J,I))**2)+SQRT((XS
     1(J,I-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2))*(SQRT((XS(J,I-1)-
     2XS(J,I))**2+(YS(J,I-1)-YS(J,I))**2)+SQRT((XP(J,I-1)-XP(J,I))**2+(Y
     3P(J,I-1)-YF(J,I))**2))+(SQRT((XS(J-1,I)-XF(J-1,I))**2+(YS(J-1,I)-Y
     4P(J-1,I))**2)+SQRT((XS(J-1,I-1)-XF(J-1,I-1))**2+(YS(J-1,I-1)-YP(J-
     51,I-1))**2))*(SQRT((XS(J-1,I-1)-XS(J-1,I))**2+(YS(J-1,I-1)-YS(J-1,
     6I))**2)+SQRT((XP(J-1,I-1)-XF(J-1,I))**2+(YP(J-1,I-1)-YF(J-1,I))**2
     7)))*(ZS(J,I)+ZS(J,I-1)+ZP(J,I)+ZP(J,I-1)-ZS(J-1,I)-ZS(J-1,I-1)-ZP(
     8J-1,I)-ZP(J-1,I-1))/32.0
      IF (LNCT.LE.56) GO TO 475
      LNCT=1
      WRITE (LOG2,85)
475   LNCT=LNCT+4
      WRITE (LOG2,480) VOL
480   FORMAT (2X,/,2X,/,40X,25HVOLUME OF BLADE SECTION =,1FE11.4,/,40X,3
     16(1H*))
      IF (IJDUM.EQ.0) GO TO 530
      WRITE (LOG2,85)
      WRITE (LOG2,485)
485   FORMAT (43X,43HBLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS,/,43X,4
     13(1H*))
      IDUM=7
      LNCT=3
      DO 525 I=1,NSTNS
      IF (IFANGS(I).EQ.0) GO TO 525
```

```
      DO 495 J=1,NLINES
      CALL D1 (RSTA(1,I),XSTA(1,I),KPTS(I),R(I,J),XDUM,1,0)
      CALL CQ (RSTA(1,I),XSTA(1,I),KPTS(I),R(I,J),XDUM,ZR(J),1,1)
      DO 490 K=1,NPOINT
      SS(K)=XS(J,K)
      RAD(K)=YS(J,K)
      XTEMP(K)=XP(J,K)
490   X(K)=YP(J,K)
      XDUM=XDUM-STACKX
      CALL D1 (SS,RAD,NPOINT,XDUM,YY1,1,1)
      CALL D1 (XTEMP,X,NPOINT,XDUM,YY2,1,1)
      W1=YY1/R(I,J)
      W2=YY2/R(I,J)
      TC(J)=ABS(ATAN(W1/SQRT(1.-W1**2))-ATAN(W2/SQRT(1.-W2**2)))/(2.*PI)
     1*FLOAT(NBLADE)
495   CONTINUE
      CALL CQ (ZCAMB(1,I),YCAMB(1,I),NLINES,ZCAMB(1,I),XDUM,RLE,NLINES,1
     1)
      IF (LNCT+IDUM+NLINES.LE.59) GO TO 500
      WRITE (LOG2,85)
      LNCT=2
500   LNCT=LNCT+IDUM+NLINES
      WRITE (LOG2,505) I,NLINES
505   FORMAT (///,48X,8HSTATION ,I2,5X,17HNUMBER OF RADII= ,I2,//,36X,6H
     1RADIUS,5X,7HSECTION,6X,4HLEAN,9X,5HBLADE,7X,5HTHETA,/,48X,5HANGLE,
     26X,5HANGLE,7X,8HBLOCKAGE,/,2X)
      DO 510 J=1,NLINES
      EPS=(THETA(J,I)-ATAN(RLE(J)))*C1
      ALPHB=ALPHA(J,I)
      ALP=(ATAN((TANPHI(I,J)*TAN(EPS/C1)+ALPHB*SQRT(1.+TANPHI(I,J)**2))/
     1(1.-TANPHI(I,J)*ZR(J))))*C1
      WRITE (LOG2,515) R(I,J),ALP,EPS,TC(J),THETA(J,I)
      IF (IPUNCH.EQ.0) GO TO 510
      WRITE (LOG3,520) R(I,J),ALP,EPS,TC(J),THETA(J,I),I,J
510   CONTINUE
515   FORMAT (30X,5F12.4)
520   FORMAT (5F12.7,2I3)
525   CONTINUE
530   IF (IFPLOT.LT.2.OR.IFPLOT.EQ.4) GO TO 535
      CALL FQ (ISTAK,PLTSZE,2,TITLE,IKDUM,IFPLOT)
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```
535   IF (IPRINT.EQ.1) GO TO 545
      LNCT=2
      WRITE (LOG2,540)
540   FORMAT (1H1,27X,74HBLADE SURFACE GEOMETRY IN CARTESIAN COORDINATES
     1 AT SPECIFIED VALUES OF 'Z',/,28X,74H*****************************
     2*********************************************)
545   IF (IPRINT.EQ.1.AND.IFPLOT.LE.1) GO TC 695
      XZ=NZ-1
      DZ=(ZOUTER-ZINNER)/XZ
      ZOUT(1)=ZINNER
      DO 550 J=3,NZ
550   ZOUT(J-1)=ZOUT(J-2)+DZ
      ZOUT(NZ)=ZCUTER
      DO 555 I=1,NPOINT
      CALL D1 (ZS(1,I),XS(1,I),NLINES,ZOUT,TEMP1,NZ,0)
      CALL D1 (ZS(1,I),YS(1,I),NLINES,ZCUT,TEMP2,NZ,0)
      CALL D1 (ZF(1,I),XP(1,I),NLINES,ZCUT,TEMP3,NZ,0)
      CALL D1 (ZF(1,I),YP(1,I),NLINES,ZOUT,TEMP4,NZ,0)
      DO 555 J=1,NZ
      XS(J,I)=TEMP1(J)
      YS(J,I)=TEMP2(J)
      XP(J,I)=TEMP3(J)
555   YP(J,I)=TEMP4(J)
      DO 560 I=1,31
      CALL D1 (ZSEMI(1,I),XSEMI(1,I),NLINES,ZOUT,TEMP1,NZ,0)
      CALL D1 (ZSEMI(1,I),YSEMI(1,I),NLINES,ZOUT,TEMP2,NZ,0)
      DO 560 J=1,NZ
      XSEMI(J,I)=TEMP1(J)
560   YSEMI(J,I)=TEMP2(J)
      DO 690 J=1,NZ
      RO=SQRT((XS(J,1)-XP(J,1))**2+(YS(J,1)-YP(J,1))**2)/2.0
      AREA=PI*RO**2/2.0
      BETA1=ATAN((YS(J,2)+YP(J,2)-YS(J,1)-YP(J,1))/(XS(J,2)+XP(J,2)-XS(J
     1,1)-XP(J,1)))
      XINT=AREA*((XP(J,1)+XS(J,1))/2.0-COS(BETA1)*4.0/(3.0*PI)*RO)
      YINT=AREA*((YP(J,1)+YS(J,1))/2.0-SIN(BETA1)*4.0/(3.0*PI)*RO)
      DO 565 I=2,NPOINT
      DELA=(SQRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)+SQRT((XS(J,I
     1-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2))*(SQRT((XS(J,I-1)-XS(J
     2,I))**2+(YS(J,I-1)-YS(J,I))**2)+SQRT((XP(J,I-1)-XP(J,I))**2+(YP(J,
```

```
     3I-1)-YP(J,I))**2))/4.0
      AREA=AREA+DELA
      XINT=XINT+DELA*(XS(J,I)+XS(J,I-1)+XP(J,I)+XP(J,I-1))/4.0
  565 YINT=YINT+DELA*(YS(J,I)+YS(J,I-1)+YP(J,I)+YP(J,I-1))/4.0
      YINT=YINT/AREA
      XINT=XINT/AREA
      X1=(XS(J,1)+XP(J,1))/2.
      Y1=(YS(J,1)+YP(J,1))/2.
      T1=SQRT((XS(J,1)-XP(J,1))**2+(YS(J,1)-YP(J,1))**2)
      F=0.
      U=0.
      DO 570 I=2,NPCINT
      T2=SQRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)
      X2=(XS(J,I)+XP(J,I))/2.
      Y2=(YS(J,I)+YP(J,I))/2.
      DELU=SQRT((X2-X1)**2+(Y2-Y1)**2)
      U=U+DELU
      TAV3=(T1**3+T2**3)/2.
      F=F+TAV3*DELU
      X1=X2
      Y1=Y2
  570 T1=T2
      TORCCN=((1./3.)*F)/(1.+(4./3.)*F/AREA/U**2)
      IX=0.0
      IY=0.0
      IXY=0.0
      DO 575 I=2,NPCINT
      XD=(SQRT((XS(J,I-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2)+SQRT((
     1XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2))/2.0
      YD=(SQRT((XS(J,I)-XS(J,I-1))**2+(YS(J,I)-YS(J,I-1))**2)+SQRT((XP(J
     1,I)-XP(J,I-1))**2+(YP(J,I)-YP(J,I-1))**2))/2.0
      IXD=YD*YD*YD*XD/12.0
      IYD=XD*XD*XD*YD/12.0
      ANG=ATAN((YS(J,I)+YP(J,I)-YS(J,I-1)-YP(J,I-1))/(XP(J,I)+XS(J,I)-XP
     1(J,I-1)-XS(J,I-1)))
      COSANG=COS(2.0*ANG)
      IXN=(IXD+IYD+(IXD-IYD)*COSANG)/2.0
      IYN=(IXD+IYD-(IXD-IYD)*COSANG)/2.0
      IXYN=0.0
      IF (ANG.NE.0.0) IXYN=((IXN-IYN)*COSANG-IXD+IYD)/(2.0*SIN(2.0*ANG))
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```
      DELA=XC*YD
      YMN=(YS(J,I)+YS(J,I-1)+YP(J,I)+YP(J,I-1))/4.0-YINT
      XMN=(XS(J,I)+XS(J,I-1)+XP(J,I)+XP(J,I-1))/4.0-XINT
      IX=IX+IXN+DELA*YMN*YMN
      IY=IY+IYN+DELA*XMN*XMN
  575 IXY=IXY+IXYN+DELA*YMN*XMN
      ANG=ATAN(2.0*IXY/(IY-IX))
      IPX=(IX+IY)/2.0+(IX-IY)/2.0*COS(ANG)-IXY*SIN(ANG)
      IPY=(IX+IY)/2.0-(IX-IY)/2.0*COS(ANG)+IXY*SIN(ANG)
      ANG=ANG/2.0*C1
      IF (IPRINT.EQ.1) GO TO 640
      IF (LNCT.LE.45) GO TO 580
      WRITE (LOG2,85)
      LNCT=1
  580 LNCT=LNCT+16
      WRITE (LOG2,585) J,ZOUT(J),AREA,XINT,YINT,IX,IY,IXY,IPX,ANG,IPY,AN
     1G
  585 FORMAT (2X,/,50X,14HSECTION NUMBER,I3,3X,5H'Z' =,F9.4,/,50X,34H***
     1*******************************,///,20X,18HSECTION PROPERTIES,7X,1
     22HSECTION AREA,26X,1H=,1PE12.4,//,45X,20HLOCATION OF CENTROID,11X,
     34HXBAR,3X,1H=,E12.4,/,45X,22HRELATIVE TO STACK AXIS,9X,4HYBAR,3X,1
     4H=,E12.4,//,45X,22HSECOND MOMENTS OF AREA,9X,2HIX,5X,1H=,E12.4,/,4
     55X,14HABOUT CENTROID,17X,2HIY,5X,1H=,E12.4,/,76X,3HIXY,4X,1H=,E12.
     64,//,45X,24HPRINCIPAL SECOND MOMENTS,7X,3HIPX,4X,1H=,E12.4,4H (AT,
     70PF7.2,21H DEGREES TO 'X' AXIS),/,45X,22HOF AREA ABOUT CENTROID,9X
     8,3HIPY,4X,1H=,1PE12.4,4H (AT,0PF7.2,21H DEGREES TO 'Y' AXIS))
      WRITE (LOG2,590) TORCON
  590 FORMAT (/,45X,18HTORSIONAL CONSTANT,20X,1H=,1PE12.4,/,2X)
      LNCT=LNCT+3
      IF (LNCT.LE.50) GO TO 595
      WRITE (LOG2,85)
      LNCT=1
  595 LNCT=LNCT+5
      WRITE (LOG2,600)
  600 FORMAT (2X,/,20X,19HSECTION COORDINATES,/,2X)
      WRITE (LOG2,605)
  605 FORMAT (31X,8HPOINT NO,5X,2HXS,12X,2HYS,16X,2HXP,12X,2HYP,/,2X)
      DO 610 I=1,NPOINT
      LNCT=LNCT+1
      IF (LNCT.LE.60) GO TO 610
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      LNCT=4                                                         A3405
      WRITE (LOG2,85)                                                A3410
      WRITE (LOG2,605)                                               A3415
610   WRITE (LOG2,615) I,XS(J,I),YS(J,I),XP(J,I),YP(J,I)             A3420
615   FORMAT (31X,I5,3X,1P2E14.5,4X,2E14.5)                          A3425
      IF (LNCT.LE.55) GO TO 620                                      A3430
      LNCT=1                                                         A3435
      WRITE (LOG2,85)                                                A3440
620   LNCT=LNCT+3                                                    A3445
      WRITE (LCG2,625)                                               A3450
625   FORMAT (2X,/,31X,8HPOINT NO,5X,5HXSEMI,9X,5HYSEMI,/,2X)        A3455
      CO 630 I=1,31                                                  A3460
      LNCT=LNCT+1                                                    A3465
      IF (LNCT.LE.60) GO TO 630                                      A3470
      WRITE (LOG2,85)                                                A3475
      WRITE (LOG2,625)                                               A3480
      LNCT=4                                                         A3485
630   WRITE (LOG2,635) I,XSEMI(J,I),YSEMI(J,I)                       A3490
635   FORMAT (31X,I5,3X,1P2E14.5)                                    A3495
640   IF (IFPLCT.LT.2) GO TO 690                                     A3500
      IF (IFPLCT.EQ.4) GO TO 660                                     A3505
      XPLOT=XS(J,1)*SCALE                                            A3510
      YPLCT=YS(J,1)*SCALE                                            A3515
      CALL PLOT (XPLOT,YPLOT,3)                                      A3520
      DO 645 I=2,NPOINT                                              A3525
      XPLOT=XS(J,I)*SCALE                                            A3530
      YPLOT=YS(J,I)*SCALE                                            A3535
645   CALL PLCT (XPLOT,YPLOT,2)                                      A3540
      DO 650 II=1,NPOINT                                             A3545
      I=NPCINT+1-II                                                  A3550
      XPLOT=XP(J,I)*SCALE                                            A3555
      YPLOT=YP(J,I)*SCALE                                            A3560
650   CALL PLOT (XPLOT,YPLOT,2)                                      A3565
      DO 655 I=2,30                                                  A3570
      XPLCT=XSEMI(J,I)*SCALE                                         A3575
      YPLOT=YSEMI(J,I)*SCALE                                         A3500
655   CALL PLCT (XPLOT,YPLOT,2)                                      A3585
      XPLOT=XS(J,1)*SCALE                                            A3590
      YPLOT=YS(J,1)*SCALE                                            A3595
      CALL PLCT (XPLOT,YPLOT,2)                                      A3600
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      GO TC 690                                                         A3605
660   CALL SYMBOL (19.9,2.0,.175,22HCARTESIAN SECTICN NO. ,0.0,22)      A3610
      XJ=J                                                              A3615
      CALL NUMBER (23.75,2.,.175,XJ,0.0,-1)                             A3620
      CALL SYMBOL (20.6,1.0,.175,10HSTAGGER = ,0.0,10)                  A3625
      STAGER=ATAN((YS(J,NFOINT)+YF(J,NPOINT)-YS(J,1)-YP(J,1))/(XS(J,NPOI A3630
     1NT)+XP(J,NFCINT)-XS(J,1)-XP(J,1)))*C1                             A3635
      CALL NUMBER (22.35,1.,.175,STAGER,0.0,3)                          A3640
      CALL PLCT (22.0,5.25,-3)                                          A3645
      SINSTG=SIN(STAGER/C1)                                             A3650
      COSSTG=COS(STAGER/C1)                                             A3655
      YPLOT=4.75                                                        A3660
      XPLOT=4.75*SINSTG/CCSSTG                                          A3665
      IF (ABS(XPLOT).LE.22.0) GC TO 665                                 A3670
      XPLOT=22.0                                                        A3675
      YPLOT=-22.0/SINSTG*COSSTG                                         A3680
665   CALL PLCT (XPLOT,YPLOT,3)                                         A3685
      XPLOT=-XPLCT                                                      A3690
      YPLOT=-YPLCT                                                      A3695
      CALL PLCT (XPLOT,YPLOT,2)                                         A3700
      XPLOT=22.0                                                        A3705
      YPLOT=-22.0*SINSTG/COSSTG                                         A3710
      IF (ABS(YPLOT).LE.4.75) GC TO 670                                 A3715
      YPLOT=-4.75                                                       A3720
      XPLOT=4.75/SINSTG*CCSSTG                                          A3725
670   CALL PLCT (XPLOT,YPLOT,3)                                         A3730
      XPLOT=-XPLCT                                                      A3735
      YPLOT=-YPLOT                                                      A3740
      CALL PLCT (XPLOT,YPLOT,2)                                         A3745
      XPLOT=SCALE*(XS(J,1)*CCSSTG+YS(J,1)*SINSTG)                       A3750
      YPLOT=SCALE*(YS(J,1)*COSSTG-XS(J,1)*SINSTG)                       A3755
      CALL PLCT (XPLOT,YPLOT,3)                                         A3760
      DO 675 I=2,NPOINT                                                 A3765
      XPLOT=SCALE*(XS(J,I)*COSSTG+YS(J,I)*SINSTG)                       A3770
      YPLOT=SCALE*(YS(J,I)*COSSTG-XS(J,I)*SINSTG)                       A3775
675   CALL PLCT (XPLOT,YPLOT,2)                                         A3780
      DO 680 II=1,NFOINT                                                A3785
      I=NPCINT+1-II                                                     A3790
      XPLOT=SCALE*(XP(J,I)*CCSSTG+YP(J,I)*SINSTG)                       A3795
      YPLOT=SCALE*(YP(J,I)*COSSTG-XP(J,I)*SINSTG)                       A3800
```

```
680   CALL PLCT (XPLOT,YPLOT,2)                                    A3805
      DO 685 I=2,30                                                A3810
      XPLOT=SCALE*(XSEMI(J,I)*CCSSTG+YSEMI(J,I)*SINSTG)            A3815
      YPLOT=SCALE*(YSEMI(J,I)*CCSSTG-XSEMI(J,I)*SINSTG)            A3820
685   CALL PLOT (XPLOT,YPLOT,2)                                    A3825
      XPLOT=SCALE*(XS(J,1)*COSSTG+YS(J,1)*SINSTG)                  A3830
      YPLOT=SCALE*(YS(J,1)*COSSTG-XS(J,1)*SINSTG)                  A3835
      CALL FLCT (XPLOT,YPLOT,2)                                    A3840
      CALL PLOT (23.0,-5.25,-3)                                    A3845
690   CONTINUE                                                     A3850
695   IF (IFPLOT.NE.0) CALL PLOTE                                  A3855
      GO TO 710                                                    A3860
700   WRITE (LOG2,705) J                                           A3865
705   FORMAT (10X,8HFAILEC  ,I2)                                   A3870
710   CONTINUE                                                     A3875
      STOP                                                         A3880
      END                                                          A3885-
```

```
      SUBROUTINE BQ (IBL,YS,YF,XS,XP,YSEMI,XSEMI,LOG2,N,IPRINT,BETA1,BET
     1A2,YZERO,T,YONE,XDEL,YDEL,Z,XNORMC,LNCT,DX,Y,CY,SIGMA,SS1,XHERE,X,
     2SS,NSTNS,R,BX,XM,YM,AM,AXIALC,ISTAK)
      REAL IX,IY,IXY,IPX,IPY,IXC,IYD,IXN,IYN,IXYN
      DIMENSION YS(15,81), YF(15,81), XS(15,81), XP(15,81), YSEMI(15,31)
     1, XSEMI(15,31), S(81), Y(100), THICK2(81), XM(82), YM(81), AM(81),
     2 XHERE(100), X(100), SS(100), R(10,15), DX(100), CY(100), SS1(100,
     33), SIGMA(100)
5     FORMAT (1H1)
      PI=3.1415926535
      C1=180.0/PI
      IF (IPRINT.EQ.2) GO TO 15
      WRITE (LOG2,10) IBL,BETA1,BETA2,YZERO,T,YONE,Z,AXIALC
10    FORMAT (1H1,44X,43HSTREAMSURFACE GEOMETRY ON STREAMLINE NUMBER,I3,
     1/45X,46(1H*),//,20X,5HBETA1,11X,1H=,F7.3,6X,20H(BLADE INLET ANGLE.
     2),/,20X,5HBETA2,11X,1H=,F7.3,6X,21H(BLADE OUTLET ANGLE.),/,20X,5HY
     3ZERO,11X,1H=,F8.5,5X,51H(BLADE LEADING EDGE RADIUS AS A FRACTION O
     4F CHORD.),/,20X,1HT,15X,1H=,F8.5,5X,49H(BLADE MAXIMUM THICKNESS AS
     5 A FRACTION OF CHORD.),/,20X,4HYONE,12X,1H=,F8.5,5X,60H(BLADE TRAI
     6LING EDGE HALF-THICKNESS AS A FRACTION OF CHORD.),/,20X,1HZ,15X,1H
     7=,F7.4,6X,59H(LOCATION OF MAXIMUM THICKNESS AS A FRACTION OF MEAN
     8LINE.),/,20X,4HCORD,12X,1H=,F7.4,6X,30H(MERIDIONAL CHORD OF SECTIO
     9N.))
15    CHORD=XNORMC/(1.0-YZERO+XNORMC*(YZERO+ABS(YONE*SIN(BETA2/C1))))
      FCSLMN=1.0-CHORD*(YZERO+ABS(YONE*SIN(BETA2/C1)))
      AX=1./99.
      DX(1)=0.
      DO 20 IK=2,100
20    DX(IK)=DX(IK-1)+AX
      CALL D1 (XM,YM,N,DX,DY,100,1)
      SIGMA(1)=0.
      DO 25 K=2,100
25    SIGMA(K)=SIGMA(K-1)+SQRT((DX(K)-DX(K-1))**2+(DY(K)-DY(K-1))**2)
      CALL D1 (DX,SIGMA,100,XM,S,N,1)
      YZERO=YZERO*CHORD/FCSLMN
      YONE=YONE*CHORD/FCSLMN
      T=T*CHORD/FCSLMN
      S(1)=0.0
      AT=(YZERO-T/2.0)/(2.0*Z**2)
      CT=(T/2.0-YZERO)*3.0/(2.0*Z)
```

```
      DT=YZERO
      ET=(YONE-T/2.0)/(1.0-Z)**3-1.5*(YZERO-T/2.0)/(Z**2*(1.0-Z))
      FT=1.5*(YZERO-T/2.0)/Z**2
      HT=T/2.0
      DO 40 J=1,N
      SN=S(J)/S(N)
      IF (SN.GT.Z) GO TO 30
      THICK2(J)=(AT*SN**2+CT)*SN+DT
      GO TO 35
   30 SN=SN-Z
      THICK2(J)=(ET*SN+FT)*SN**2+HT
   35 FYPR=1./SQRT(1.+AM(J)**2)
      YPRIME=AM(J)
      XS(IBL,J)=(XM(J)-THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN
      YS(IBL,J)=(YM(J)+THICK2(J)*FYPR)*FCSLMN
      XP(IBL,J)=(XM(J)+THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN
      YP(IBL,J)=(YM(J)-THICK2(J)*FYPR)*FCSLMN
      AM(J)=ATAN(AM(J))*C1
      XM(J)=(XM(J)+YZERO)*FCSLMN
      YM(J)=YM(J)*FCSLMN
      THICK2(J)=THICK2(J)*FCSLMN
   40 S(J)=S(J)*FCSLMN
      YZERO=YZERO*FCSLMN
      AREA=PI/2.0*YZERO**2
      XINT=YZERO*(1.0-COS(BETA1/C1)*4.0/(3.0*PI))*AREA
      YINT=-4.0/(3.0*PI)*YZERO*AREA*SIN(BETA1/C1)
      DO 45 J=2,N
      DELA=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))
      AREA=AREA+DELA
      XINT=XINT+DELA*(XM(J)+XM(J-1))/2.0
   45 YINT=YINT+DELA*(YM(J)+YM(J-1))/2.0
      XBAR=XINT/AREA
      YBAR=YINT/AREA
      XBARB=XBAR
      YBARB=YBAR
      YBAR=YBAR+YDEL/AXIALC
      XBAR=XBAR+XDEL/AXIALC
      CALL D1 (XM,AM,N,DX,SS1(1,1),100,1)
      DO 50 IK=1,100
      SS1(IK,1)=TAN(SS1(IK,1)/C1)
```

```
      Y(IK)=DY(IK)*FCSLMN
50    SIGMA(IK)=DX(IK)*FCSLMN+YZERO
      CALL D1 (SIGMA,Y,100,DX,DY,100,1)
      CALL D1 (SIGMA,SS1(1,1),100,DX,Y,100,1)
      CALL D1 (DX,DY,100,XBAR,XAB,1,1)
      CALL C1 (DX,Y,100,XEAR,XBC,1,1)
      XBAR=XBARB
      YBAR=YBARB
      IX=0.0
      IY=0.0
      IXY=0.0
      CO 55 J=2,N
      DELA=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))
      IXD=(THICK2(J)+THICK2(J-1))**3*(S(J)-S(J-1))/12.0
      IYD=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))**3/12.0
      CCSANG=CCS((AM(J)+AM(J-1))/C1)
      IXN=(IXD+IYD+(IXD-IYD)*COSANG)/2.0
      IYN=(IXD+IYD-(IXD-IYD)*COSANG)/2.0
      IXYN=0.0
      IF ((AM(J)+AM(J-1)).NE.C.C) IXYN=((IXN-IYN)*CCSANG-IXD+IYD)/(2.0*S
     1IN((AM(J)+AM(J-1))/C1))
      IX=IX+IXN+CELA*((YM(J)+YM(J-1))/2.0-YEAR)**2
      IY=IY+IYN+CELA*((XM(J)+XM(J-1))/2.0-XEAR)**2
55    IXY=IXY+IXYN+DELA*(YBAR-(YM(J)+YM(J-1))/2.0)*(XBAR-(XM(J)+XM(J-1))
     1/2.0)
      ANG=ATAN(2.0*IXY/(IY-IX))
      IPX=(IX+IY)/2.0+(IX-IY)/2.0*COS(ANG)-IXY*SIN(ANG)
      IPY=(IX+IY)/2.0-(IX-IY)/2.0*COS(ANG)+IXY*SIN(ANG)
      ANG=ANG/2.0*C1
      STAGER=ATAN(YM(N)/XM(N))*C1
      XML=XM(N)
      YML=YM(N)
      CAMBER=BETA1-BETA2
      IF (IPRINT.EQ.2) GO TO 95
      LNCT=47
      WRITE (LCG2,60) CHORD,STAGER,CAMBER,AREA,XBAR,YEAR,IX,IY,IXY,ANG,I
     1PX,ANG,IPY,ANG
60    FORMAT (/,16X,100HNCRMALISEC RESULTS - ALL THE FOLLCWING REFER TO
     1ABLACE HAVING A MERIDICNAL CHORC PROJECTICN OF UNITY,/,16X,100(1H*
     2),//20X,11HBLADE CHCRD,4X,1H=,F7.4,//,20X,16HSTAGGER ANGLE  =,F7.3
```

```
     3,//,20X,16HCAMBER ANGLE   =,F7.3,//,20X,16HSECTION AREA   =,F7.5,/
     4/,20X,45HLOCATION OF CENTROID RELATIVE TO LEADING EDGE,//,30X,6HXB
     5AR =,F8.5,/,30X,6HYBAR =,F8.5,//,20X,37HSECOND MOMENTS OF AREA ABO
     6UT CENTROID,//,30X,6HIX   =,F8.5,/,30X,6HIY   =,F8.5,/,30X,6HIXY
     7=,F8.5,//,20X,58HANGLE OF INCLINATION OF (ONE) PRINCIPAL AXIS TO '
     8X' AXIS =,F7.3,//,20X,47HPRINCIPAL SECOND MOMENTS OF AREA ABOUT CE
     9NTROID,//,30X,6HIPX  =,F7.5,6X,3H(AT,F7.3,15H WITH 'X' AXIS),/,30X
     $,6HIPY  =,F7.5,6X,3H(AT,F7.3,15H WITH 'Y' AXIS),//)
65    FORMAT (27X,5HPOINT,8X,24HM E A N L I N E  D A T A,13X,23HSURFACE
     1COORDINATE DATA,/,27X,6HNUMBER,5X,1HX,7X,1HY,5X,15HANGLE THICKNESS
     2,9X,2HXS,6X,2HYS,6X,2HXP,6X,2HYP,//)
      WRITE (LOG2,65)
      DO 75 J=1,N
      IF (LNCT.NE.60) GO TO 70
      WRITE (LOG2,5)
      WRITE (LOG2,65)
      LNCT=4
70    LNCT=LNCT+1
      TM=THICK2(J)*2.0
75    WRITE (LOG2,80) J,XM(J),YM(J),AM(J),TM,XS(IBL,J),YS(IBL,J),XP(IBL,
     1J),YP(IBL,J)
80    FORMAT (27X,I3,F13.5,F8.5,F7.3,F8.5,F16.5,3F8.5)
      DO 85 J=1,N
      XM(J)=XS(IBL,J)
      YM(J)=YS(IBL,J)
      AM(J)=XP(IBL,J)
85    THICK2(J)=YP(IBL,J)
      WRITE (LOG2,90) IBL
90    FORMAT (1H1,45X,33HNORMALISED PLOT OF SECTION NUMBER,I3,/,2X)
      CALL EQ (N,LOG2,XM,YM,AM,THICK2)
95    A2=AXIALC**2
      A4=A2**2
      IX=IX*A4
      IY=IY*A4
      IXY=IXY*A4
      IPX=IPX*A4
      IPY=IPY*A4
      IF (ISTAK.GT.1) GO TO 100
      XBAR=ISTAK
      IF (ISTAK.EQ.0) YBAR=0.
```

```
      IF (ISTAK.EQ.1) YBAR=YML
  100 RLE=YZERO*AXIALC
      CHORD=CHORD*AXIALC
      AREA=AREA*A2
      XC=RLE-XBAR*AXIALC-XDEL
      YC=-YBAR*AXIALC-YDEL
      IF (IPRINT.EQ.2) GO TO 120
      WRITE (LOG2,105) CHORD,RLE,XC,YC,AREA,IX,IY,IXY,IPX,ANG,IPY,ANG
  105 FORMAT (1H1,31X,69HDIMENSIONAL RESULTS - ALL RESULTS REFER TO A BL
     1ADE OF SPECIFIED CHORD,/,32X,69H*********************************
     2************************************,//,20X,11HBLADE CHORD,4X,1H=,1
     3PE12.5,//,20X,10HL.E.RADIUS,5X,1H=,1PE12.5,8X,14HCENTERED AT X=,1P
     4E13.5,3H Y=,1PE13.5,//,20X,16HSECTION AREA    =,1PE12.5,//,20X,37HS
     5ECOND MOMENTS OF AREA ABOUT CENTROID,//,30X,6HIX    =,1PE12.5,/,30X
     6,6HIY    =,1PE12.5,/,30X,6HIXY   =,1PE12.5,//,20X,47HPRINCIPAL SECON
     7D MOMENTS OF AREA ABOUT CENTROID,//,30X,6HIPX   =,1PE12.5,5H  (AT,0
     8PF7.3,15H WITH 'X' AXIS),/,30X,6HIPY   =,1PE12.5,5H  (AT,0PF7.3,15H
     9 WITH 'Y' AXIS),//)
      WRITE (LOG2,110)
      WRITE (LOG2,115)
  110 FORMAT (124H     PT       SUCTION------SURFACE          PRESSURE-----SU
     1RFACE          PT       SUCTION------SURFACE          PRESSURE-----SUR
     2FACE)
  115 FORMAT (4X,2HNO,8X,1HX,13X,1HY,13X,1HX,13X,1HY,12X,2HNO,8X,1HX13X,
     11HY,13X,1HX,13X,1HY,//)
      LNCT=24
  120 DO 135 J=1,N
      XS(IBL,J)=(XS(IBL,J)-XBAR)*AXIALC-XDEL
      YS(IBL,J)=(YS(IBL,J)-YBAR)*AXIALC-YDEL
      XP(IBL,J)=(XP(IBL,J)-XBAR)*AXIALC-XDEL
      YP(IBL,J)=(YP(IBL,J)-YBAR)*AXIALC-YDEL
      IF (IPRINT.EQ.2) GO TO 135
      IF ((J/2)*2.NE.J) GO TO 135
      IF (LNCT.NE.60) GO TO 125
      LNCT=4
      WRITE (LOG2,5)
      WRITE (LOG2,110)
      WRITE (LOG2,115)
  125 LNCT=LNCT+1
      JM1=J-1
```

```
      WRITE (LOG2,130) JM1,XS(IBL,JM1),YS(IBL,JM1),XP(IBL,JM1),YP(IBL,JM
     11),J,XS(IBL,J),YS(IBL,J),XP(IBL,J),YP(IBL,J)
  130 FORMAT (3X,I3,4(2X,1PE12.5),6X,I3,4(2X,1PE12.5))
  135 CONTINUE
      IF (IPRINT.EQ.2) GO TO 150
      IF (LNCT.GT.24) WRITE (LOG2,140)
  140 FORMAT (1H1)
      IF (LNCT.GT.24) LNCT=2
      LNCT=LNCT+5
      WRITE (LOG2,145)
  145 FORMAT (2X,/,48X,37HPOINTS DESCRIBING LEADING EDGE RADIUS,//,48X,9
     1HPOINT NO.,6X,1HX,13X,1HY,/,2X)
  150 EPS=BETA1+180.0
      DO 160 J=1,31
      XSEMI(IBL,J)=XC-RLE*SIN(EPS/C1)
      YSEMI(IBL,J)=YC+RLE*COS(EPS/C1)
      EPS=EPS-6.0
      IF (IPRINT.EQ.2) GO TO 160
      WRITE (LOG2,155) J,XSEMI(IBL,J),YSEMI(IBL,J)
      LNCT=LNCT+1
  155 FORMAT (48X,I5,1PE17.5,1PE14.5)
  160 CONTINUE
      SSURF=AXIALC
      SS2=EX-AXIALC*XBAR-XDEL
      SBAR=SS2+AXIALC*XBARB+XDEL
      DO 165 IK=1,100
  165 SS(IK)=SS(IK)-SBAR
      CALL D1 (SS,X,100,0.,SBAR,1,1)
      CALL D1 (XHERE,R(1,IBL),NSTNS,SBAR,RXBAR,1,0)
      XBARC=XBAR
      YBARC=YBAR
      XBAR=XBARB+XDEL/AXIALC
      YBAR=YBARB+YDEL/AXIALC
      SS1(1,1)=SS(1)
      S23=AXIALC/99.
      SS(1)=SS(1)+SS2
      DO 170 IK=2,100
      SS1(IK,1)=SS(IK)
  170 SS(IK)=SS(IK-1)+S23
      SIGMAC=(XAB-YBAR)/RXBAR*AXIALC
```

```
      DO 175 IK=2,100
      IF (XBAR.EQ.DX(IK)) GO TO 185
      IF (XBAR.GT.DX(IK-1).ANC.XBAR.LT.DX(IK)) GC TC 190
175   CONTINUE
      WRITE (LOG2,180)
180   FORMAT (1H1,23H XBAR CANNCT BE LOCATED)
185   SIGMA(IK)=SIGMAC
      KL=IK+1
      GO TC 195
190   KL=IK
      SIGMA(IK-1)=SIGMAO
195   SSDUM=SS(KL-1)
      SS(KL-1)=0.
      YP1=XBC
      RX1=RXBAR
      DO 200 IK=KL,100
      XSURF=SS2+DX(IK)*SSURF+SS1(1,1)
      CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)
      CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)
      CALL C1 (SS1(1,1),X,100,XSURF,XDUM,1,1)
      CALL D1 (XHERE,R(1,IBL),NSTNS,XDUM,RX2,1,0)
      SIGMA(IK)=SIGMA(IK-1)+(Y(IK)/RX2+YP1/RX1)/2.*(SS(IK)-SS(IK-1))
      YP1=Y(IK)
200   RX1=RX2
      SS(KL-1)=SSDUM
      SSDUM=SS(KL)
      SIGDUM=SIGMA(KL)
      SIGMA(KL)=SIGMAC
      SS(KL)=0.
      RX1=RXBAR
      YP1=XBC
      KM=KL-1
      DO 205 IK=1,KM
      KJ=KL-IK
      XSURF=SS2+DX(KJ)*SSURF+SS1(1,1)
      CALL D1 (SS1(1,1),X,100,XSURF,XDUM,1,1)
      CALL D1 (XHERE,R(1,IBL),NSTNS,XDUM,RX2,1,0)
      SIGMA(KJ)=SIGMA(KJ+1)-(Y(KJ)/RX2+YP1/RX1)/2.*(SS(KJ+1)-SS(KJ))
      YP1=Y(KJ)
205   RX1=RX2
```

```
      SIGMA(KL)=SIGDUM
      SS(KL)=SSDUM
      DO 210 IK=1,100
210   SS(IK)=SS1(IK,1)
      XBAR=XBARC
      YBAR=YBARC
      DO 215 IK=1,N
      SS1(IK,1)=SS2+((XS(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
215   SS1(IK,2)=SS2+((XP(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
      DO 220 IK=1,31
220   SS1(IK,3)=SS2+((XSEMI(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
      CALL D1 (SS,X,100,SS1(1,1),SS1(1,1),N,1)
      CALL D1 (SS,X,100,SS1(1,2),SS1(1,2),N,1)
      CALL D1 (SS,X,100,SS1(1,3),SS1(1,3),31,1)
      IF (ISTAK.GT.1) GO TO 230
      IF (ISTAK.EQ.1) SIGMAO=SIGMA(100)
      IF (ISTAK.EQ.0) SIGMAO=SIGMA(1)
      DO 225 IK=1,100
225   SIGMA(IK)=SIGMA(IK)-SIGMAO
230   DO 235 IK=1,100
      DX(IK)=(DX(IK)-XBAR)*AXIALC-XDEL
235   DY(IK)=(DY(IK)-YBAR)*AXIALC-YDEL
      DO 245 MK=1,3
      IF (MK.EQ.3) NNN=31
      IF (MK.EQ.1.OR.MK.EQ.2) NNN=N
      DO 240 IK=1,NNN
      IF (MK.EQ.1) YP1=YS(IBL,IK)
      IF (MK.EQ.2) YP1=YP(IBL,IK)
      IF (MK.EQ.3) YP1=YSEMI(IBL,IK)
      IF (MK.EQ.1) RX1=XS(IBL,IK)
      IF (MK.EQ.2) RX1=XP(IBL,IK)
      IF (MK.EQ.3) RX1=XSEMI(IBL,IK)
      CALL D1 (DX,DY,100,RX1,RXBAR,1,1)
      DELLY=YP1-RXBAR
      CALL D1 (XHERE,R(1,IBL),NSTNS,SS1(IK,MK),RAB,1,0)
      DELSIG=DELLY/RAB
      CALL D1 (DX,SIGMA,100,RX1,XAB,1,1)
240   SS1(IK,MK)=XAB+DELSIG
245   CONTINUE
      RETURN
      END
```

```
      SUBRCUTINE CQ (XDATA,YDATA,NDATA,XIN,YOUT,YPRIME,NXY,NNOT)
      REAL M
      DIMENSICN A(65), B(65), D(65), M(65), XDATA(1), YDATA(1), XIN(1),
     1YOUT(1), YPRIME(1)
      IF (NDATA-2) 120,5,35
5     IF (NNOT-1) 10,20,10
10    DO 15 I=1,NXY
15    YOUT(I)=((YCATA(2)-YDATA(1))/(XDATA(2)-XDATA(1)))*(XIN(I)-XDATA(1)
     1)+YDATA(1)
20    IF (NNOT) 120,120,25
25    DC 30 I=1,NXY
30    YPRIME(I)=(YDATA(2)-YDATA(1))/(XDATA(2)-XCATA(1))
      GO TC 120
35    CONTINUE
      E1=1.0
      E2=1.0
      A(1)=1.0
      B(1)=-E1
      D(1)=0.0
      N=NDATA-1
      DC 40 I=2,N
      A(I)=(XDATA(I+1)-XDATA(I-1))/3.0-(XDATA(I)-XDATA(I-1))*B(I-1)/(6.0
     1*A(I-1))
      B(I)=(XDATA(I+1)-XDATA(I))/6.0
40    D(I)=(YDATA(I+1)-YDATA(I))/(XDATA(I+1)-XDATA(I))-(YCATA(I)-YCATA(I
     1-1))/(XCATA(I)-XDATA(I-1))-(XDATA(I)-XDATA(I-1))*D(I-1)/6.0/A(I-1)
      A(NDATA)=-E2
      B(NDATA)=1.0
      D(NDATA)=0.0
      M(NDATA)=A(NDATA)*D(N)/(A(NCATA)*B(N)-A(N)*B(NDATA))
      DO 45 II=2,NDATA
      I=NDATA+1-II
45    M(I)=(D(I)-B(I)*M(I+1))/A(I)
      J=1
      I=1
50    IF (XIN(I)-XDATA(1)) 95,95,55
55    IF (XIN(I)-XDATA(J+1)) 70,70,60
60    IF (J+1-NDATA) 65,70,70
65    J=J+1
      GO TC 55
```

```
70    IF (XIN(I)-XDATA(NDATA)) 75,110,110
75    DX=XDATA(J+1)-XDATA(J)
      IF (NWCT-1) 80,85,80
80    YOUT(I)=M(J)/(6.0*DX)*(XDATA(J+1)-XIN(I))**3+M(J+1)/(6.0*DX)*(XIN(
     1I)-XDATA(J))**3+(XDATA(J+1)-XIN(I))*(YDATA(J)/DX-M(J)/6.0*DX)+(XIN
     2(I)-XDATA(J))*(YDATA(J+1)/DX-M(J+1)/6.0*DX)
      IF (NWOT) 85,90,85
85    YPRIME(I)=(-M(J)*(XDATA(J+1)-XIN(I))**2/2.0+M(J+1)*(XIN(I)-XDATA(J
     1))**2/2.0+YDATA(J+1)-YDATA(J))/DX-(M(J+1)-M(J))/6.0*DX
90    I=I+1
      IF (I-NXY) 50,50,120
95    YDASH=(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))-(M(1)/3.0+M(2)/6.0)*
     1(XDATA(2)-XDATA(1))
      IF (NWCT-1) 100,105,100
100   YOUT(I)=YDATA(1)-YDASH*(XDATA(1)-XIN(I))
      IF (NWOT) 105,90,105
105   YPRIME(I)=YDASH
      GO TO 90
110   YDASH=(YDATA(NDATA)-YDATA(N))/(XDATA(NDATA)-XDATA(N))+(M(NDATA)/3.
     10+M(N)/6.0)*(XDATA(NDATA)-XDATA(N))
      IF (NWCT-1) 115,105,115
115   YOUT(I)=YDATA(NDATA)+YDASH*(XIN(I)-XDATA(NDATA))
      IF (NWOT) 105,90,105
120   RETURN
      END
```

```
      SUBROUTINE D1 (XDATA,YDATA,NDATA,XIN,YOUT,NXY,NTYPE)
      REAL M
      DIMENSION M(15), A(15), B(15), D(15), XDATA(1), YDATA(1), XIN(1),
     1YOUT(1)
      IF (NDATA-1) 5,5,15
5     DO 10 I=1,NXY
10    YOUT(I)=YDATA(1)
      RETURN
15    IF (NDATA-2) 25,25,20
20    IF (NTYPE) 90,90,25
25    J=1
      I=1
30    IF (XIN(I)-XDATA(2)) 65,65,35
35    IF (XIN(I)-XDATA(NDATA-1)) 40,70,70
40    IF (XIN(I)-XDATA(J)) 50,60,45
45    IF (XIN(I)-XDATA(J+1)) 60,60,50
50    J=J+1
      IF (J-NDATA) 40,55,55
55    J=1
      GO TO 40
60    YOUT(I)=YDATA(J)+(YDATA(J+1)-YDATA(J))/(XDATA(J+1)-XDATA(J))*(XIN(
     1I)-XDATA(J))
      GO TO 75
65    YOUT(I)=YDATA(1)+(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))*(XIN(I)-X
     1DATA(1))
      GO TO 75
70    YOUT(I)=YDATA(NDATA-1)+(YDATA(NDATA)-YDATA(NDATA-1))/(XDATA(NDATA)
     1-XDATA(NDATA-1))*(XIN(I)-XDATA(NDATA-1))
75    IF (I-NXY) 80,85,85
80    I=I+1
      GO TO 30
85    RETURN
90    A(1)=1.0
      B(1)=0.0
      D(1)=0.0
      N=NDATA-1
      DO 95 I=2,N
      A(I)=(XDATA(I+1)-XDATA(I-1))/3.0-(XDATA(I)-XDATA(I-1))*B(I-1)/(6.0
     1*A(I-1))
      B(I)=(XDATA(I+1)-XDATA(I))/6.0
```

```
95    D(I)=(YDATA(I+1)-YDATA(I))/(XDATA(I+1)-XDATA(I))-(YDATA(I)-YDATA(I
     1-1))/(XDATA(I)-XDATA(I-1))-(XDATA(I)-XDATA(I-1))*D(I-1)/6.0/A(I-1)
      M(NDATA)=0.0
      DO 100 II=2,N
      I=NDATA+1-II
100   M(I)=(D(I)-B(I)*M(I+1))/A(I)
      M(1)=0.0
      J=1
      I=1
105   IF (XIN(I)-XDATA(1)) 115,130,110
110   IF (XIN(I)-XDATA(NDATA)) 140,135,120
115   JP=1
      KP=2
      GO TO 125
120   JP=NDATA
      KP=NDATA-1
125   YPRIME=(YDATA(KP)-YDATA(JP))/(XDATA(KP)-XDATA(JP))-M(KP)/6.0*(XDAT
     1A(KP)-XDATA(JP))
      YOUT(I)=YDATA(JP)+(XIN(I)-XDATA(JP))*YPRIME
      GO TO 175
130   YOUT(I)=YDATA(1)
      GO TO 175
135   YOUT(I)=YDATA(NDATA)
      GO TO 175
140   IF (XIN(I)-XDATA(J)) 150,160,145
145   IF (XIN(I)-XDATA(J+1)) 170,165,150
150   J=J+1
      IF (J-NDATA) 140,155,155
155   J=1
      GO TO 140
160   YOUT(I)=YDATA(J)
      GO TO 175
165   YOUT(I)=YDATA(J+1)
      GO TO 175
170   DX=XDATA(J+1)-XDATA(J)
      YOUT(I)=M(J)/(6.0*DX)*(XDATA(J+1)-XIN(I))**3+M(J+1)/(6.0*DX)*(XIN(
     1I)-XDATA(J))**3+(XDATA(J+1)-XIN(I))*(YDATA(J)/DX-M(J)/6.0*DX)+(XIN
     2(I)-XDATA(J))*(YDATA(J+1)/DX-M(J+1)/6.0*DX)
175   IF (I-NXY) 180,185,185
180   I=I+1
      GO TO 105
185   RETURN
      END
```

```
      SUBROUTINE EQ (IX,LOG1,X1,Y1,X2,Y2)
      REAL LINE
      DIMENSION X1(1), Y1(1), X2(1), Y2(1), LINE(121), XNUM(13)
      DATA SYMBOL/1H*/,DASH/1H-/,CROSS/1H+/,BLANK/1H /,XI/1HI/
      YMIN=Y1(1)
      XMIN=X1(1)
      YMAX=YMIN
      XMAX=XMIN
      DO 5 I=1,IX
      IF (Y2(I).LT.YMIN) YMIN=Y2(I)
      IF (Y2(I).GT.YMAX) YMAX=Y2(I)
      IF (X2(I).LT.XMIN) XMIN=X2(I)
      IF (X2(I).GT.XMAX) XMAX=X2(I)
      IF (Y1(I).GT.YMAX) YMAX=Y1(I)
      IF (X1(I).GT.XMAX) XMAX=X1(I)
    5 CONTINUE
      IF (XMAX.EQ.XMIN.OR.YMIN.EQ.YMAX) GO TO 85
      YH=YMAX+(YMAX-YMIN)/25.0
      YL=YMIN-(YMAX-YMIN)/25.0
      XH=XMAX+(XMAX-XMIN)/38.3333
      XL=XMIN-(XMAX-XMIN)/38.3333
      IF ((YH-YL)/(XH-XL).GT.0.75) XH=1.3333*(YH-YL)+XL
      IF ((YH-YL)/(XH-XL).LT.0.75) YH=0.75*(XH-XL)+YL
      XMAX=(XMIN+XMAX-XH+XL)/2.0
      XH=XH-XL+XMAX
      XL=XMAX
      XMAX=(YMIN+YMAX-YH+YL)/2.0
      YH=YH-YL+XMAX
      YL=XMAX
      XMAX=ABS(XH)
      XMIN=ABS(XL)
      YMIN=ABS(YL)
      YMAX=ABS(YH)
      IF (XMIN.GT.XMAX) XMAX=XMIN
      IF (YMIN.GT.YMAX) YMAX=YMIN
      XMAX=ALOG10(XMAX)
      YMAX=ALOG10(YMAX)
      IF (XMAX.LT.0.0) XMAX=XMAX-1.0
      IF (YMAX.LT.0.0) YMAX=YMAX-1.0
      MX=-XMAX
```

```
      MY=-YMAX
      WRITE (LOG1,10) MX,MY
10    FORMAT (20X,46HSCALES - 'X' IS SHOWN TIMES 10 TC THE POWER OF,I3,4
     10H   'Y' IS SHOWN TIMES 10 TO THE POWER OF,I3,/)
      YINC=(YH-YL)/54.0
      YINC2=YINC/2.0
      XRANGE=XH-XL
      DO 70 KLINE=1,55
      IF (KLINE.EQ.1.OR.KLINE.EG.55) GO TC 25
      DO 15 L=2,120
15    LINE(L)=BLANK
      IF (KLINE.EQ.7.OR.KLINE.EQ.13.OR.KLINE.EQ.19.CR.KLINE.EQ.25.CR.KLI
     1NE.EC.31.OR.KLINE.EC.37.OR.KLINE.EQ.43.CR.KLINE.EO.49) GC TO 20
      LINE(1)=XI
      LINE(121)=XI
      GO TC 40
20    LINE(1)=DASH
      LINE(121)=DASH
      GO TC 40
25    DO 30 L=2,120
30    LINE(L)=DASH
      LINE(1)=CRCSS
      LINE(121)=CROSS
      DO 35 L=11,111,10
35    LINE(L)=XI
      GC TC 60
40    DO 50 I=1,IX
      IF (Y2(I).GT.YH+YINC2.OR.Y2(I).LE.YH-YINC2) GC TO 45
      L=(X2(I)-XL)/XRANGE*120.0+1.5
      LINE(L)=SYMBOL
45    IF (Y1(I).GT.YH+YINC2.OR.Y1(I).LE.YH-YINC2) GO TO 50
      L=(X1(I)-XL)/XRANGE*120.0+1.5
      LINE(L)=SYMBOL
50    CONTINUE
      TF (KLINE.EQ.1.CR.KLINE.EG.7.OR.KLINE.EQ.13.OR.KLINE.EQ.19.OR.KLIN
     1E.EQ.25.OR.KLINE.EQ.31.CR.KLINE.EQ.37.OR.KLINE.EQ.43.OR.KLINE.EQ.4
     29.OR.KLINE.EQ.55) GC TC 60
      WRITE (LOG1,55) LINE
55    FCRMAT (8X,121A1)
      GO TC 70
```

```
60    YNUM=YH*10.0**MY
      WRITE (LOG1,65) YNUM,LINE
65    FORMAT (1X,F6.3,1X,121A1)
70    YH=YH-YINC
      XNUM(1)=XL*10.0**MX
      XINC=((XH-XL)/12.0)*10.0**MX
      DO 75 I=2,13
75    XNUM(I)=XNUM(I-1)+XINC
      WRITE (LOG1,80) XNUM
80    FORMAT (6X,12(F6.3,4X),F6.3)
      RETURN
85    WRITE (LOG1,90)
90    FORMAT (//,35X,54HNC PLCT HAS BEEN MACE BECAUSE 'X' CR 'Y' RANGE I
     1S ZERO)
      RETURN
      END
```

```
      SUBRCUTINE FQ (ISTAK,PLTSZE,ITRIG,TITLE,IKDUM,IFPLOT)
      DIMENSION TITLE(8)
      IF (ITRIG.EQ.2.AND.IFPLCT.NE.2) CALL FLCT (PLTSZE,0.,-3)
      PLTTIT=PLTSZE*.1
      IF (ISTAK.LT.2) GO TO 5
      BAL=.35*PLTSZE
      XLEN1=.3*PLTSZE
      XLEN2=XLEN1
      YLEN1=.25*PLTSZE
      YLEN2=-1.*YLEN1
      XBACK1=-1.9
      XBACK2=-6.2
      GO TC 25
5     IF (ISTAK.EQ.0) GO TO 10
      XLEN1=.70*PLTSZE
      XLEN2=.15*PLTSZE
      XBACK1=-1.9-.20*PLTSZE
      XBACK2=-6.2-.20*PLTSZE
      IF (IKDUM.EQ.1) GO TO 15
      GO TO 20
10    CONTINUE
      XLEN1=.15*PLTSZE
      XLEN2=.70*PLTSZE
      XBACK1=-1.9+.20*PLTSZE
      XBACK2=-6.2+.20*PLTSZE
      IF (IKDUM.EQ.1) GO TO 20
15    BAL=.25*PLTSZE
      YLEN1=.50*PLTSZE
      YLEN2=-.15*PLTSZE
      GO TO 25
20    BAL=.50*PLTSZE
      YLEN1=.15*PLTSZE
      YLEN2=-.50*PLTSZE
25    CONTINUE
      YBACK1=-(.35+BAL)
      YBACK2=YBACK1-.01*PLTSZE-.175
      CALL PLOT (0.0,-PLTSZE,-3)
      CALL PLCT (7.0,PLTTIT,-3)
      CALL PLCT (0.0,BAL,3)
      CALL PLCT (XLEN1,BAL,-2)
```

```
      CALL PLCT (XLEN2,0.0,2)
      CALL PLCT (0.0,YLEN1,3)
      CALL PLCT (0.0,YLEN2,2)
      GO TO (30,35), ITRIG
30    CALL SYMBOL (XBACK1,YBACK1,.175,22HSTREAMSURFACE SECTIONS,0.0,22)
      GO TC 40
35    XBACK1=XBACK1+0.35
      CALL SYMBOL (XBACK1,YBACK1,.175,18HCARTESIAN SECTIONS,0.0,18)
40    CALL SYMBCL (XBACK2,YBACK2,.175,TITLE,0.0,72)
      RETURN
      END
```

4. PROGRAM LOGIC

The calculation procedure which has been described in this report is performed primarily in the main program and Subroutine BQ. The calculations regarding the construction of the camber line, the stacking of the streamsurface blade sections, and the determination of manufacturing sections are performed in the main program. Subroutine BQ applies the thickness distribution to the camber line and determines quantities necessary to obtain the Cartesian coordinates of the section from the streamsurface coordinates. Subroutine D1 is the curve-fitting routine, and CQ is used to determine slopes of various spline curves at particular points. EQ produces the line-printer section plot in the printed portion of the output, and FQ produces axes on the section plots for IFPLOT = 1, 2, or 3.

A description of the calculation procedure employed in the main program and in Subroutine BQ is described below. Each step is keyed to its location in the program by the parenthetical deck serialization.

1. The input data is read and printed. (A155-A680)

2. If precision plotting is specified, the plot is initialized, and axes produced if IFPLOT = 1 or 3. (A695-A710)

3. A loop which creates a section on each streamsurface is commenced. (A715)

4. The axial locations of the intersections of a particular streamsurface with the computing stations describing the blade are determined. The meridional streamsurface length is obtained as described in Equation (1). (A720-A780)

5. The parameters relating to the streamsurface blade section are interpolated (or extrapolated) from the input tables. If NSPEC = 1, they are taken to be radially uniform. If NSPEC = 2, linear interpolation is used; if NSPEC = 3, spline-curve interpolation is employed. (A785-A840)

6. The loop to determine the optimal camber line is initiated. (A855)

7. The first estimate of true chord is calculated per Equation (2), and the solidity as in Equation (3). (A870-A910)

8. The incidence angle and extra deviation applicable to the particular section are obtained by interpolation of the radius at the leading edge of the streamsurface in the input tables. (A915-A920)

9. The section angle at the leading edge is determined as in Equation (6). (A925)

10. The quantities required for the deviation angle calculation are obtained by interpolation from various figures of Reference 2. (A935-A960)

11. The deviation angle is calculated using Equation (5). (A995-A1000)

12. The section angle at the trailing edge is calculated using Equation (7), and at internal points using Equation (8), with fractions of deviation obtained by radial interpolation from the input distributions based on the streamsurface radius at the trailing edge of the blade. (A1020-A1085)

13. A camber line is constructed of cubic segments following the analysis of Equations (9) - (15) for the initial value of S/R_o. The number of inflection points is determined. (A1090-A1350)

14. The iteration on solidity is performed until the tolerance is within the prescribed limit. (A1355-A1395)

15. Steps 13 and 14 are repeated for IPASS-1 values of the S/R_o parameter. (A1400-A1450)

16. The range of S/R_o with the minimum number of inflection points is established. (A1480-A1600)

17. Steps 13, 14 and 15 are repeated for finer increments of the S/R_o parameter in the range determined in 16. The maximum value of the minimum radius of curvature in this range is determined. (A1645-A1690)

18. Still finer increments of S/R_o on either side of the S/R_o value which produced the maximum value of the minimum radius of curvature in 17 are examined to find the optimal S/R_o value. (A1730-A1745)

19. The details of the optimal camber line are printed if IPRINT = 0 or 1. (A1755-A1810)

20. The normalized chord length of the optimal camber line is computed. (A1820)

21. The total streamsurface length is calculated. (A1830-A1890)

22. If IPRINT = 0 or 1, the parameters defining the section are printed. (B65-B115)

23. The coefficients of the two thickness equations are computed. (B175-B220)

24. At each point of the camber line, the corresponding coordinates on each blade surface are obtained from the coordinates and slope of the camber line, and the appropriate thickness, scaled for an overall section meridional chord of unity. (B225-B310)

25. The section area and centroid location are determined. (B315-B365)

26. The camber line is redefined in terms of 100 points to assure sufficient points for accurate linear interpolation in the determination of Φ (Figure 1), needed for the eventual Cartesian coordinate determination. (B380-B440)

27. The various streamsurface section properties are determined. (B445-B560)

28. If IPRINT = 0 or 1, details of the normalized blade section and a line-printer plot are produced. (B575-B750)

29. Sectional properties are scaled to produce the "dimensional" results. (B755-B830)

30. If IPRINT = 0 or 1, the section information is printed. (B840-B1095)

31. The coordinates of 31 points describing the leading edge are determined. (B1070-B1080)

32. The origin of the coordinate system is shifted to the stack axis, and the relative Φ values for the blade surfaces are determined. (B1120-B1595)

33. If IFPLOT = 1 or 3, the streamsurface section plot is produced. (A1950-A2040)

34. If the calculations for aerodynamic analysis are required, various items related to the camber line are stored. (A2045-A2095)

35. The Cartesian coordinates for each point on the section surface are computed, and printed if IPRINT = 0 or 1. (A2100-A2435)

36. The loop initiated in 3 is repeated for each streamsurface. (A2440)

37. Unless IPRINT = 1, the volume of the blade is computed and printed. (A2445-A2555)

38. If specified, the calculations for aerodynamic analysis are performed and printed, and punched if IPUNCH = 1. (A2560-A2790)

39. If IFPLOT = 2 or 3, the axes are drawn and titled for the superimposed plot of the manufacturing sections. (A2800)

40. If no output relating to manufacturing sections is specified by either IFPLOT or IPRINT, the remainder of the program is bypassed. Alternatively, if printed details of the manufacturing sections are specified, a heading is printed. (A2805-A2835)

41. The location of each of the manufacturing planes is determined. (A2840-A2865)

42. The (Cartesian) coordinates of each point on the blade surface are obtained by spline-curve interpolation at each of the manufacturing sections. (A2870-A2945)

43. A loop that is performed for each manufacturing section is initiated. This loop contains the determination of section properties and the output of results for the section. If IPRINT = 0 or 2, section properties and coordinates are printed. (A2950-A3495)

44. If IFPLOT = 2 or 3, a plot of the manufacturing sections is produced. (A3510-A3605)

45. If IFPLOT = 4, an individual plot of the manufacturing sections is made. The axes are rotated clockwise until the chord line is horizontal. The angle of rotation is indicated as the stagger angle. (A3610-A3845)

46. The loop initiated in Step 43 for each manufacturing section is terminated. (A3850)

47. If precision plots have been made, the plotting is terminated. (A3855)

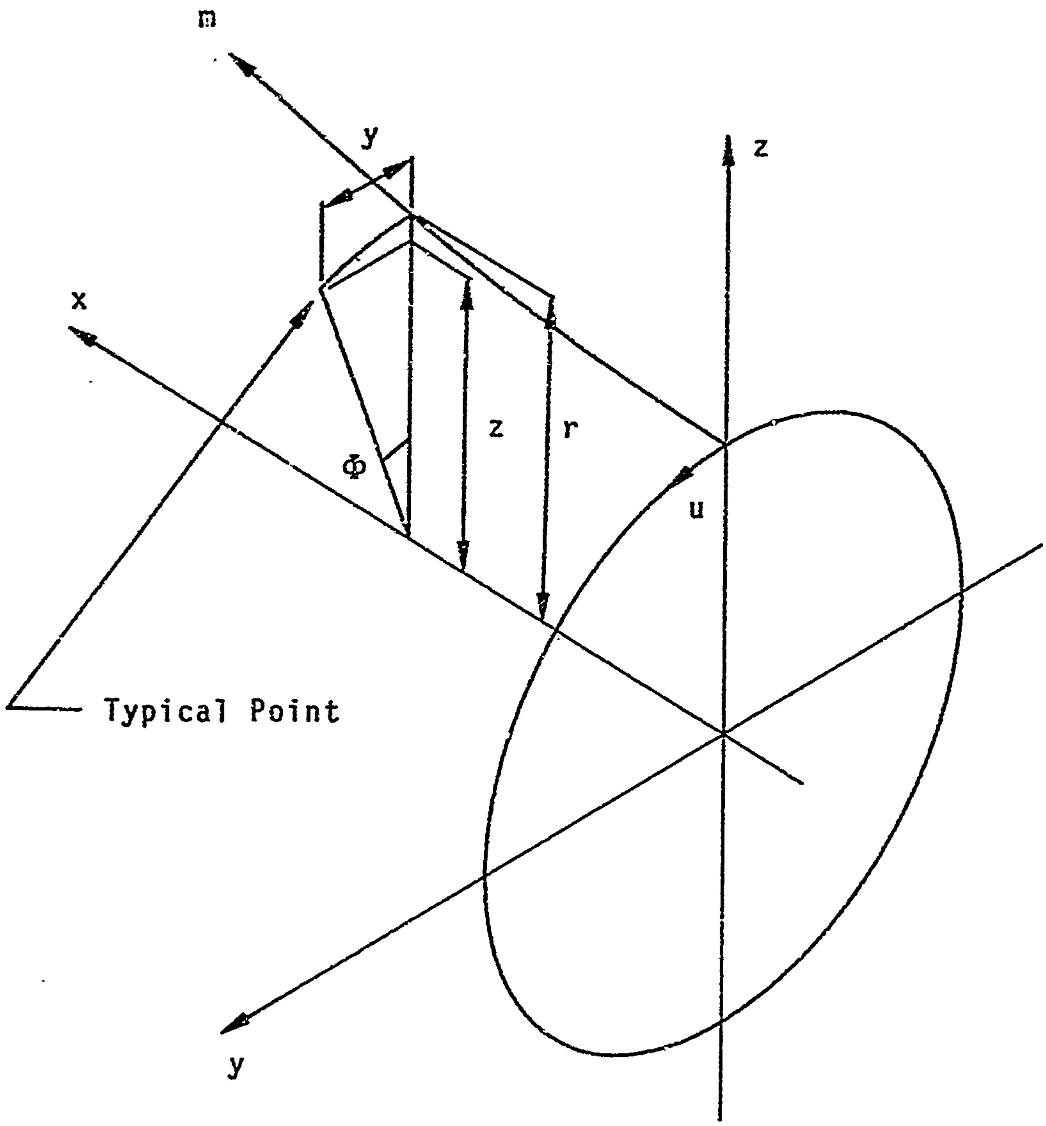

Figure 1. Cartesian and Streamsurface Coordinates of a Point

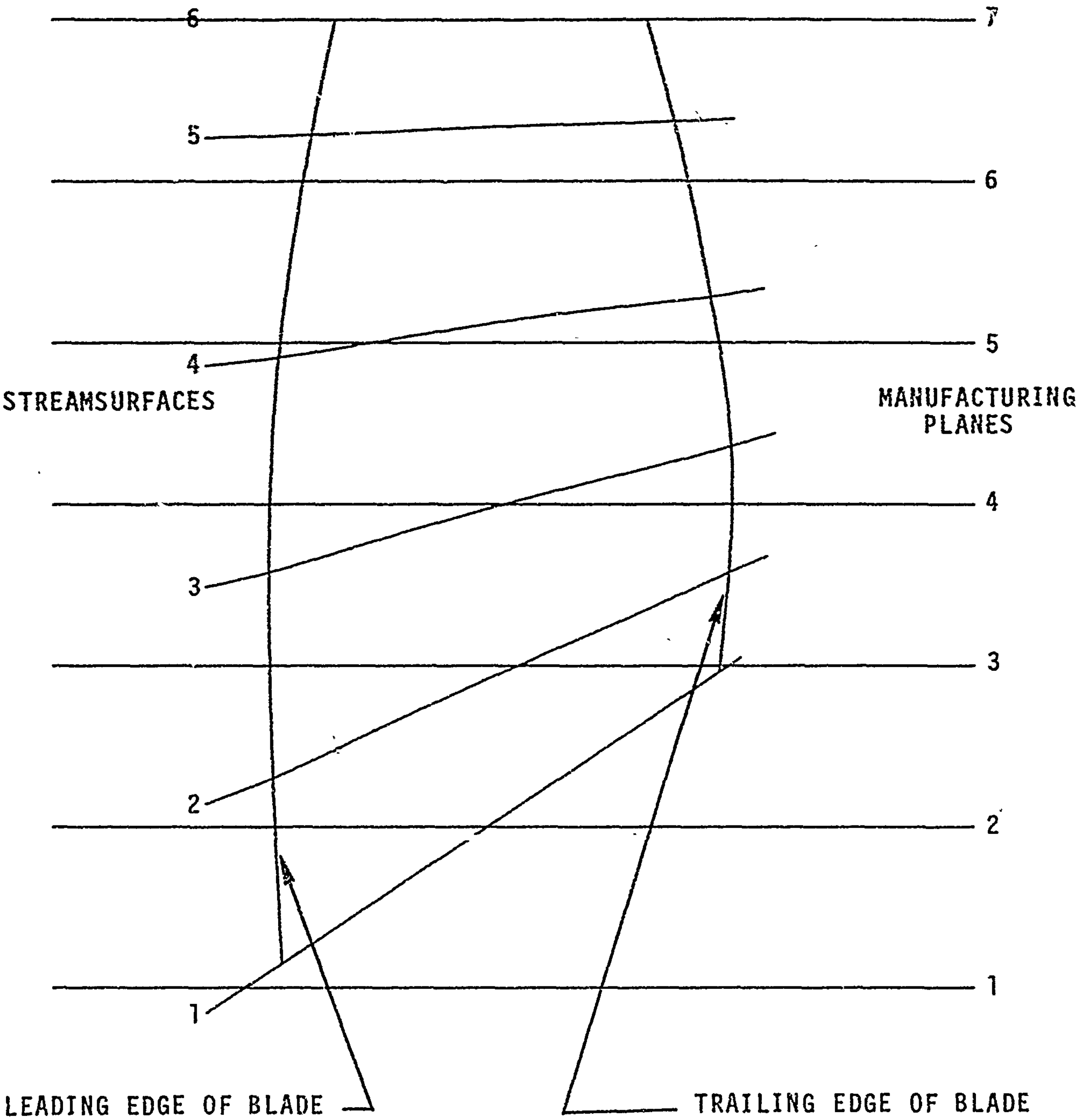

Figure 2. Locations of Streamsurfaces and Manufacturing Planes for Example Blade Design

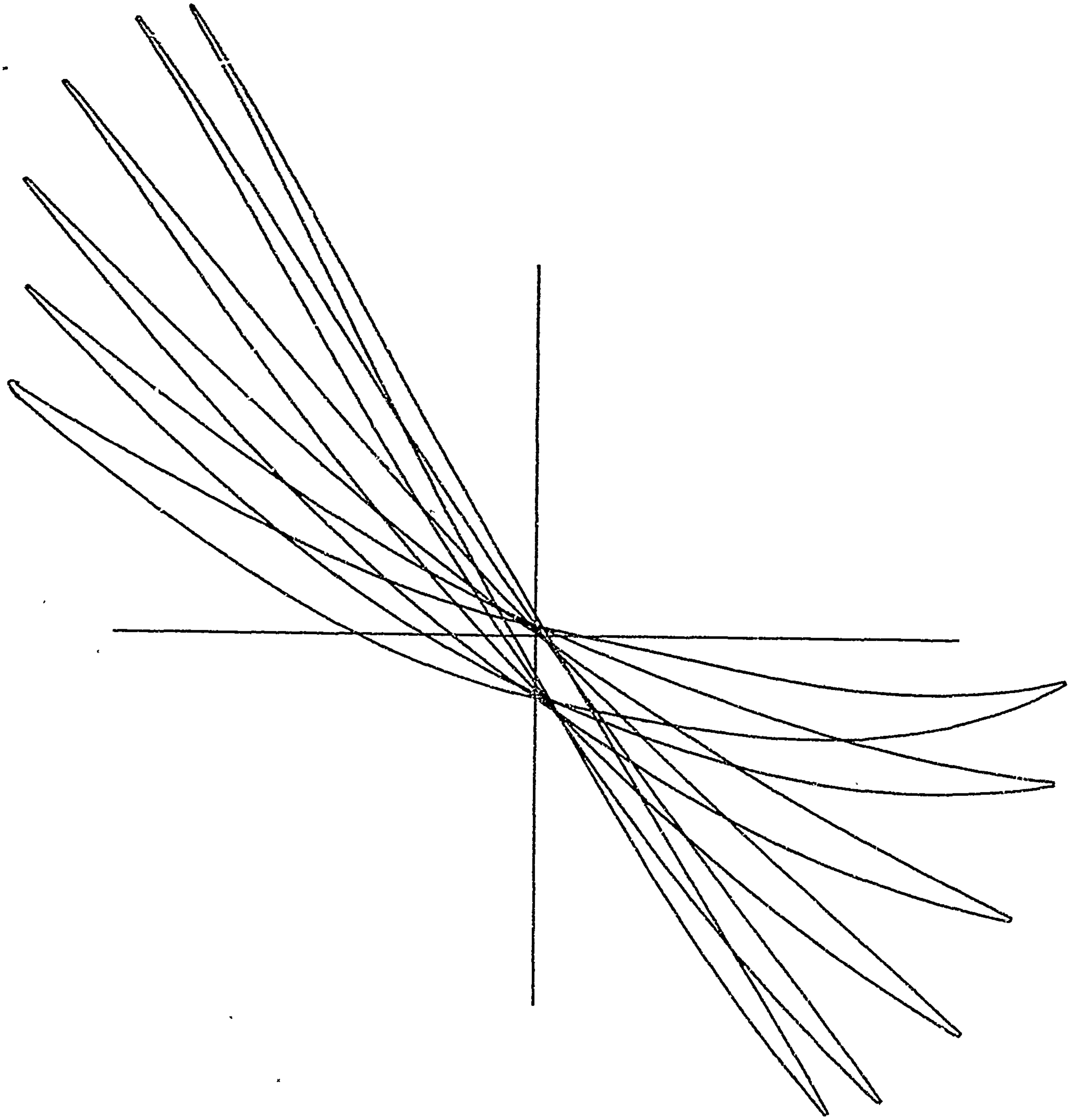

Figure 3, Example Blade Design: Streamsurface Sections

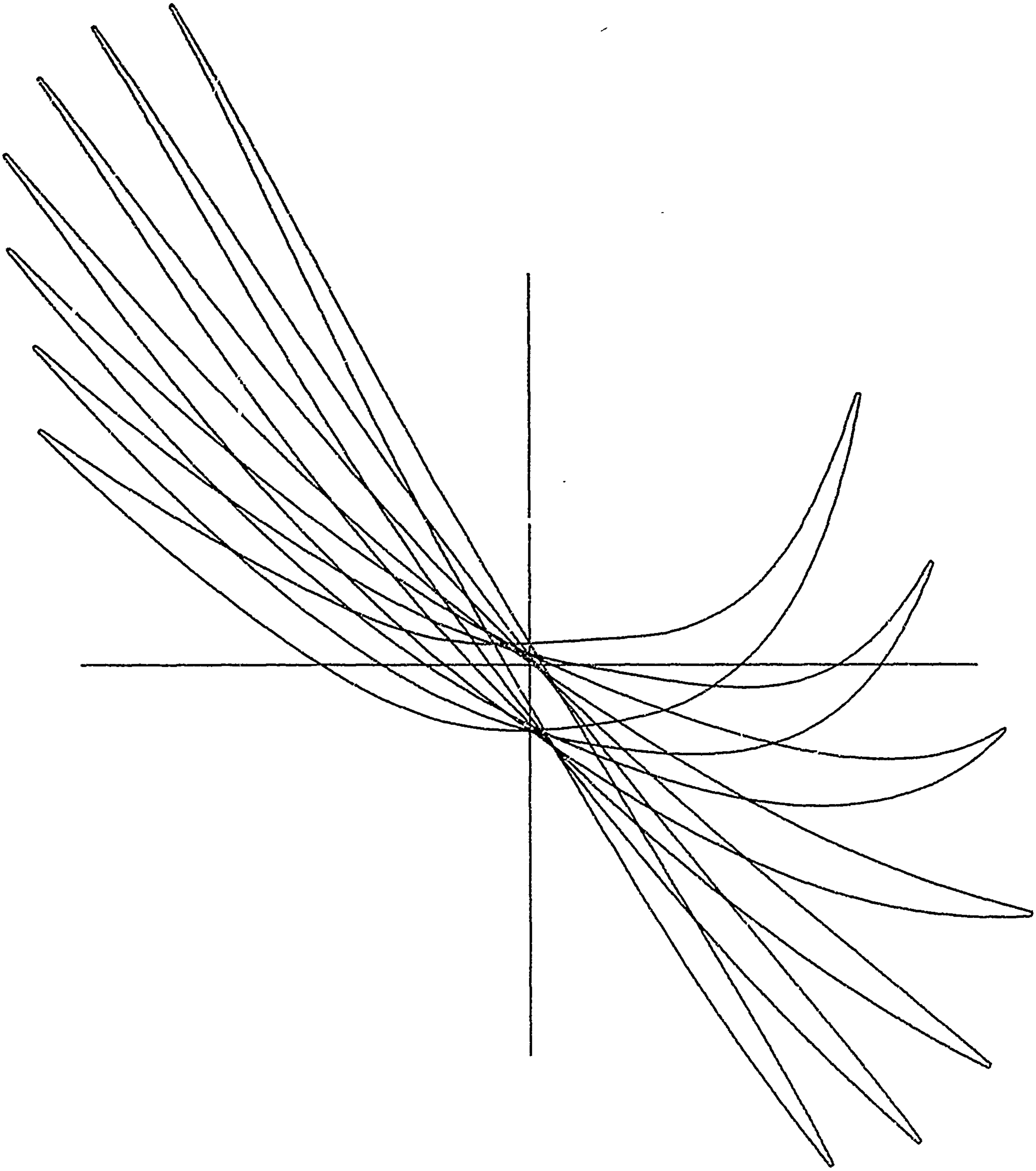

Figure 4. Example Blade Design:
Cartesian Sections

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